



National Aeronautics and Space Administration



# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project Subcommittee Final

Presented by: Mr. Chuck Johnson, Mr. Jim Griner, Ms. Kelly Hayhurst, Mr. Jay Shively, Ms. Maria Consiglio, Mr. Eric Muller, Mr. Jim Murphy, and Mr. Sam Kim



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 27, 2012



National Aeronautics and Space Administration



# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

**Presented by: Mr. Chuck Johnson**

**Manager, UAS Integration in the NAS Project**



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 27, 2012



# Outline



- Project Overview
  - What has changed since the last briefing December 20, 2011?
- Separation Assurance/Sense and Avoid Interoperability Subproject (SSI)
- Certification Subproject
- Communications Subproject
- Human Systems Integration Subproject (HSI)
- Integrated Test and Evaluation Subproject (IT&E)



# Project Overview



## **Changes since the last briefing to the NAC Aeronautics UAS Subcommittee on December 20, 2011**

- Changes to Subproject Focus in SSI and Certification
- Project Technical Challenges
- Changes to Project Management Processes
- Changes in the UAS Community
- Update on Project Outreach and Partnerships





# Project Overview

## Change to SSI Subproject

- Previously SA
- Added more emphasis on SAA
  - Re-evaluated DoD emphasis
  - FAA and RTCA request
- Added more emphasis on Interoperability between SA and SAA
- Less emphasis on airborne self separation
  - Scope/timing



# Project Overview



## Changes to Certification Subproject

- “Virtual” Certification Objective added
  - FAA request
  - RFI issued
    - Several Responses received
    - FAA was part of evaluation process



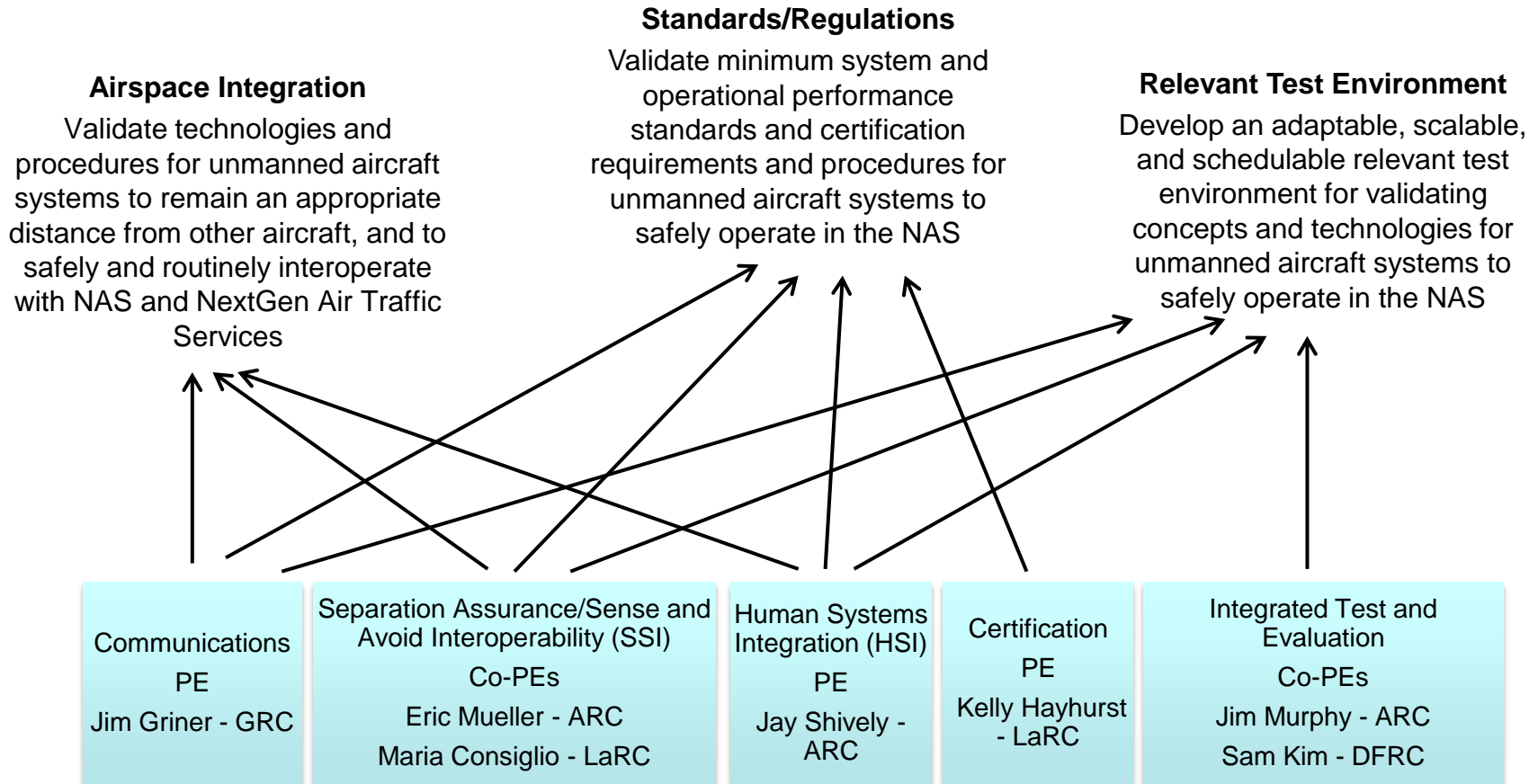
# Technical Challenges



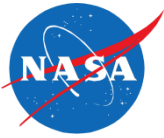
- Airspace Integration
  - Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services (ATS)
- Standards/Regulations
  - Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS
- Relevant Test Environment
  - Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Project Alignment to Address Technical Challenges



**PE – Project Engineer**



# Airspace Integration Technical Challenge



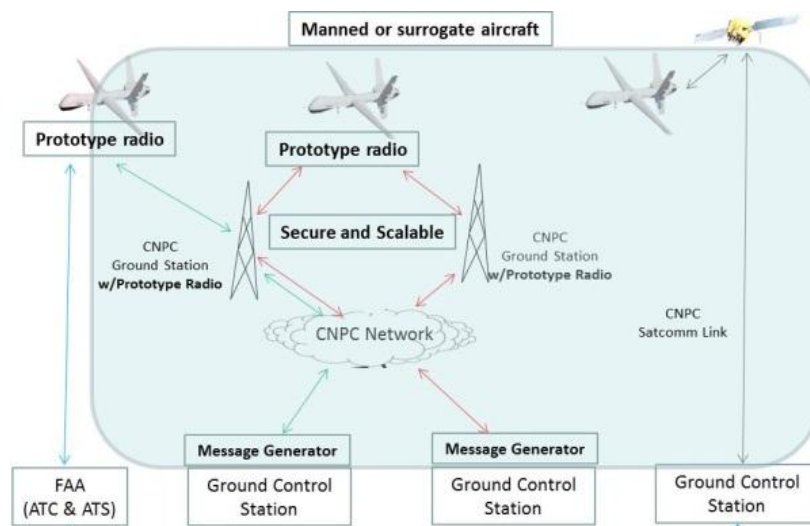
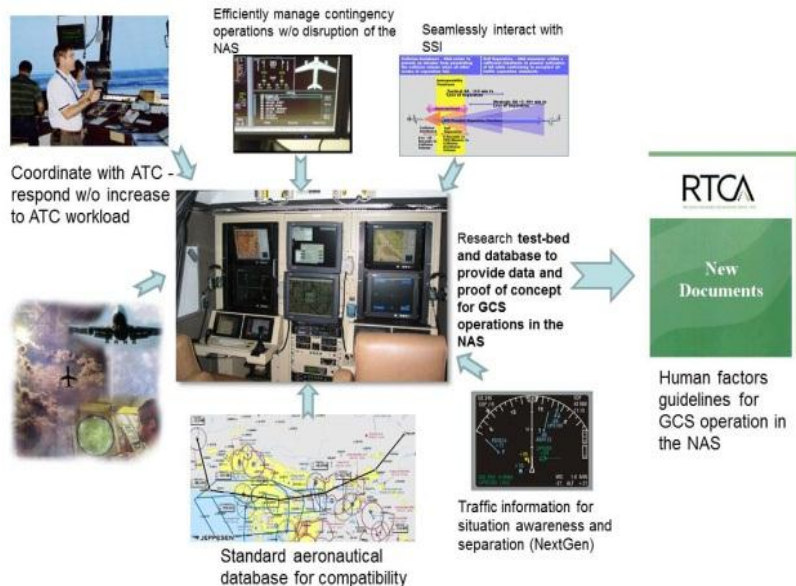
- Barriers Being Addressed by NASA
  - Uncertainty surrounding the ability of UAS to interoperate in air traffic control (ATC) environments and maintain safe separation from other aircraft in the absence of an on-board pilot
  - Lack of requirements for Sense and Avoid (SAA) systems and their interoperability with Separation Assurance (SA) functions
  - Lack of standards and guidelines with respect to UAS display/information
  - Lack of civil safety of flight frequency spectrum allocation for UAS control and non-payload communication (CNPC) data link communications
- Project Contributions to Advance the State of the Art (SOA)
  - We will analyze capacity, efficiency and safety impacts of SAA-equipped UAS in the ATC environment to validate the requirements for SAA and SA/SAA interoperability through simulation and flight tests
  - We will evaluate ground control station (GCS) system human intervention in automated systems to inform and validate standards for UAS GCSs through prototyping, simulation and flight tests
  - We will develop and validate candidate UAS CNPC system prototype proposed performance requirements to validate that candidate civil UAS spectrum is secure, scalable, and suitable for safety-of-flight operations



# Airspace Integration Technical Challenge



Notional depiction of overlapping detection look-ahead times for different SA and SAA functions (not to scale).  
Look-ahead times vary with different algorithms.





# Standards/Regulations Technical Challenge



- Barriers Being Addressed by NASA
  - Lack of standards and guidelines with respect to UAS display/information
  - Lack of GCS design requirements to operate in the NAS
  - Lack of validated regulations, standards, and practices for safe, secure, and efficient UAS control and non payload data link communications including integration with air traffic control communications
  - Lack of safety-related data available to support decision making for defining airworthiness requirements
  - Lack of airworthiness requirements specific to the full range of UAS, or for their avionics systems or other components
- Project Contributions to Advance the State of the Art
  - We will determine the required information to be displayed in the GCS to support the development of standards and guidelines through prototyping and simulation
  - We will analyze integration of UAS CNPC system and ATC communications to validate recommendations for regulations and standards
  - We will collect and analyze UAS hazard and risk related data to support safety case recommendations for the development of certification/regulation development
  - We will conduct a “virtual” type design certification effort to develop a “UAS playbook” for industry to obtain type design certificates





# Standards/Regulations Technical Challenge



## Title 14 Code of Federal Regulations a.k.a. Federal Aviation Regulations (FARs)

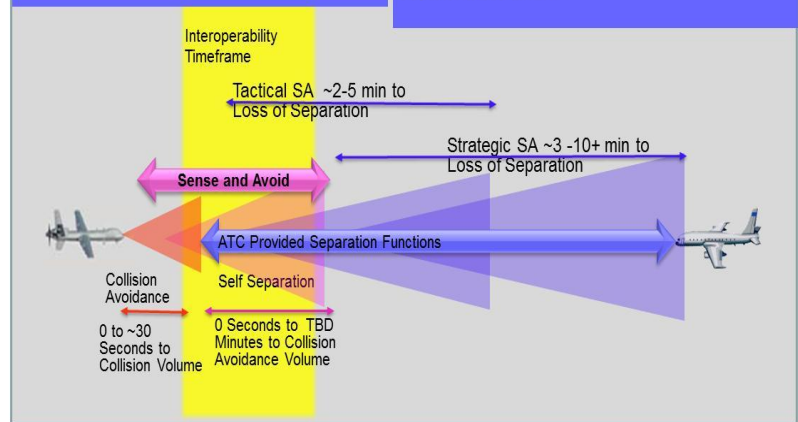


No person may operate an aircraft unless it is in an **airworthy condition** (FAR 91.7a)

- conforms to its type design and is in a condition for safe operation (FAR 3.3)
- What is the best approach to prescribing airworthiness requirements on UAS, especially their avionics? By categories?
- What does existing data from UAS failures/incidents/accidents tell us to help us know what regulation is needed?
- What would the certification process look like for a UAS? By example...

Collision Avoidance – SAA action to prevent an intruder from penetrating the collision volume when all other modes of separation fail.

Self Separation – SAA maneuver by the UAS pilot within a sufficient timeframe to prevent activation of CA while conforming to accepted air traffic separation standards.



Notional depiction of overlapping detection look-ahead times for different SA and SAA functions (not to scale).  
Look-ahead times vary with different algorithms.

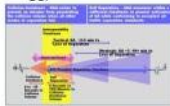


Coordinate with ATIS - respond w/o increase to ATIS workload

Efficiently manage contingency operations w/o disruption of the NAS



Seamlessly interact with SSI



Research test-bed and database to provide data and proof of concept for GCS operations in the NAS



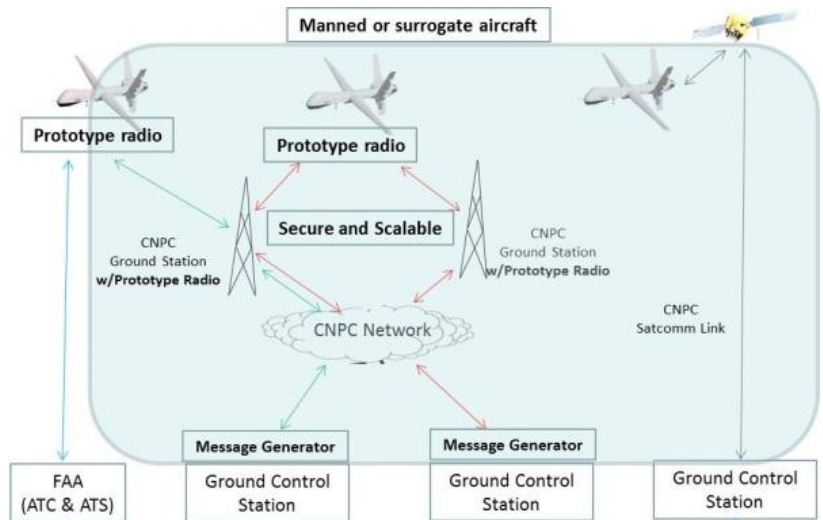
Standard aeronautical database for compatibility



Traffic information for situation awareness and separation (NextGen)



Human factors guidelines for GCS operation in the NAS



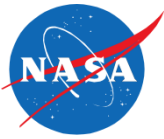
Possible Future ATS and ATC Ground Connectivity



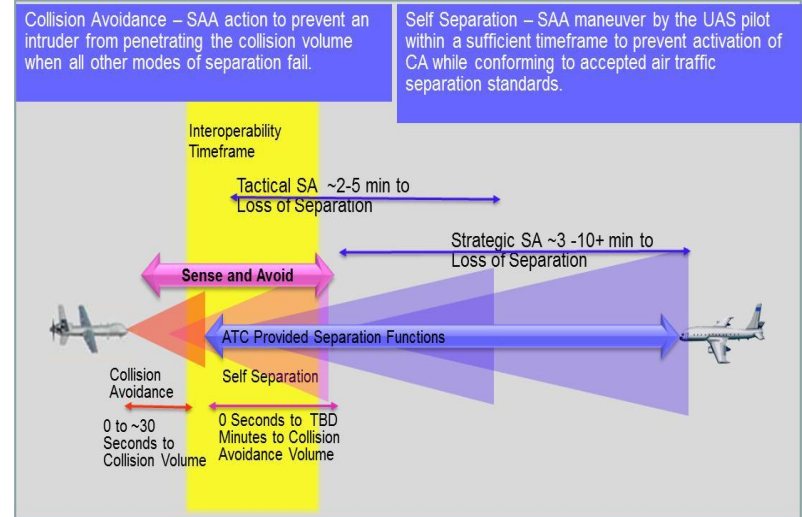
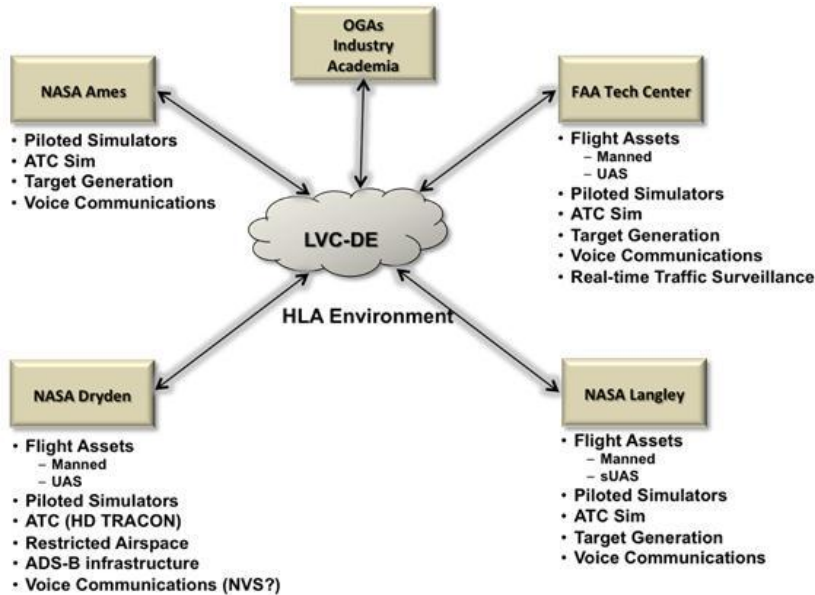
# Relevant Test Environment Technical Challenge



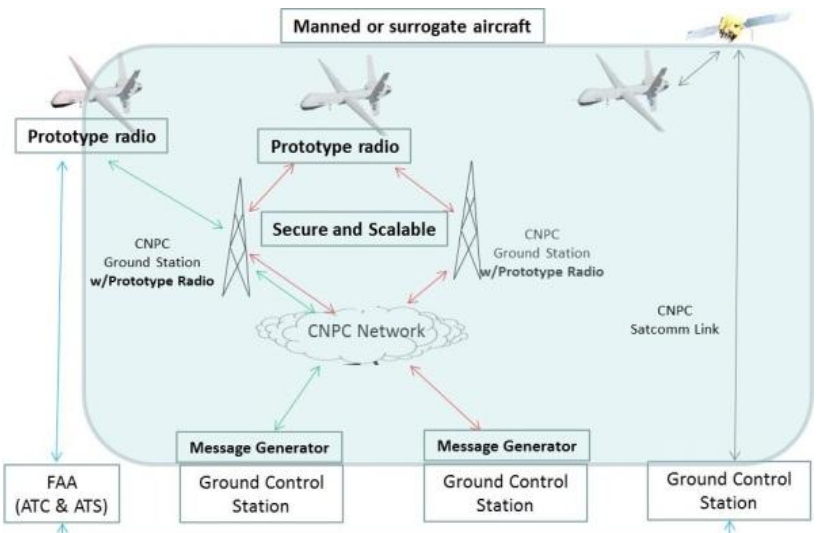
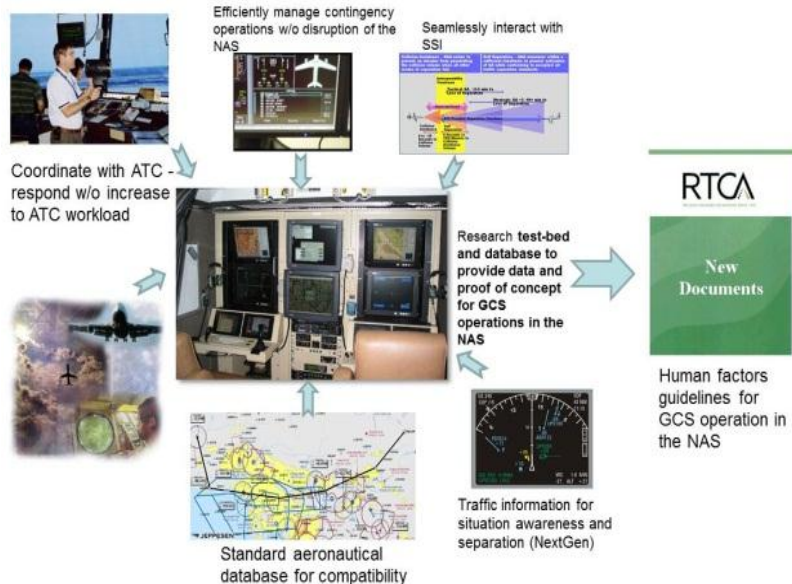
- Barriers Being Addressed by NASA
  - Lack of an adaptable, scalable, and schedulable operationally relevant test infrastructure/environment for evaluating UAS SSI, HSI, and CNPC NASA UAS/NAS subproject concepts and technology developments (IT&E)
- Project Contributions to Advance the State of the Art
  - We will develop a relevant test environment to support evaluation of UAS concepts and technologies using a Live Virtual Constructive – Distributed Environment (LVC-DE)
  - We will instantiate a GCS with display/information to demonstrate compliance with requirements
  - We will verify a CNPC system prototype in a relevant and mixed traffic environment to support the allocation of spectrum for UAS safety of flight operations



# Relevant Test Environment Technical Challenge



Notional depiction of overlapping detection look-ahead times for different SA and SAA functions (not to scale).  
Look-ahead times vary with different algorithms.



Possible Future ATS and ATC Ground Connectivity



# UAS Project Decisional and Status Forums



## UAS Management Review Board (UAS MRB)

**Chair:** Chuck Johnson

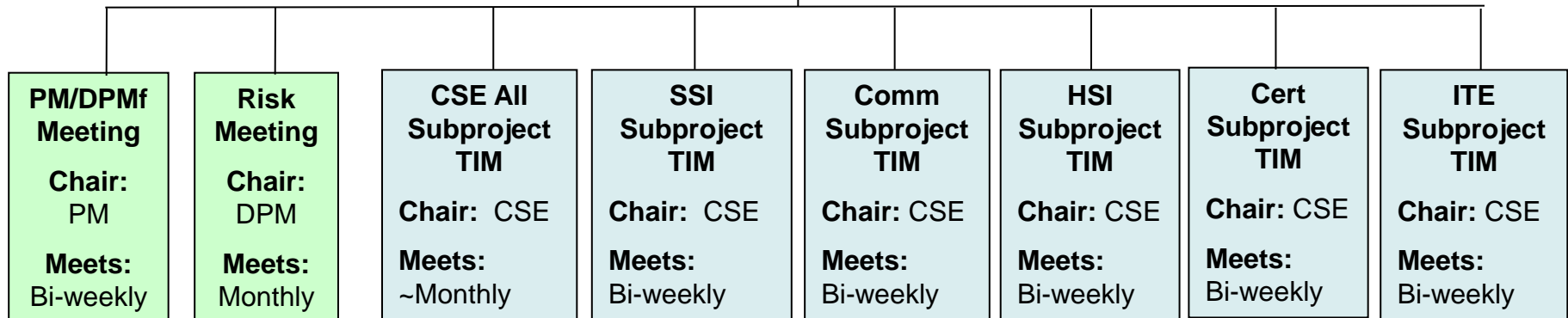
**Meets:** Monthly

**UAS Change Management Approvals for:**

- Risk Management Assessments
- Milestone Variance
- Cost/Technical Performance Variance
- Change/Data Management

**Technical**

**Programmatic**





# Risk Management



- Actively managing 18 risks
- One Integrated Systems Research Program Risk for UAS
  - Changes in project focus due to external influences
- Two Project top risks
  - Realism of predicted UAS mission profiles and NAS UAS traffic estimates
  - Overload of information to UAS pilots/operators
- One accepted risk
  - Budget restriction impacting travel plans
- Target criticality (Likelihood and Consequence) in the Green zone for all risks



# Project Risk Projection as of June 25, 2012



## Current

Risk Matrix						
L I K E L I H O O D	5		01.01.0002			
	4		04.01.0002, 04.04.0004	04.04.0003, 05.01.0003		
	3		04.02.0005, 04.04.0001	01.01.0003, 04.02.0002, 05.01.0004	05.01.0001, 05.01.0002	
	2		04.02.0003, 04.02.0006	01.01.0001 01.01.0004	04.01.0003	
	1					
		1	2	3	4	5
		CONSEQUENCE				

## Target (After Mitigations Complete)

Risk Matrix						
L I K E L I H O O D	5		01.01.0002			
	4	04.01.0002, 04.04.0004				
	3					
	2	04.04.0001	01.01.0003, 01.01.0004, 04.04.0003			
	1	04.01.0003, 04.02.0002, 04.02.0003, 04.02.0005, 04.02.0006, 05.01.0003	05.01.0001, 05.01.0004	01.01.0001	05.01.0002	
		1	2	3	4	5
		CONSEQUENCE				





# Project Schedule



Milestone Name	2011			2012				2013				2014				2015				2016			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Conduct Initial Government / Industry Meeting to define National Strategy for UAS Integration	▲																						
Provide Spectrum Requirements (LOS/BLOS Studies) to WP5B or WRC			▲																				

**FY12 APG [Project ID 31701]**

**Develop FY13 APG [Project ID 3265]**

**Separate Complete flight evaluations to assess the capabilities of the Live**

**Separate FY14 APG [Project ID 3220]**

**Conduct a human-in-the-loop (HiTL) simulation where UAS aircraft are mixed with manned aircraft and subjected to a range of test conditions.**

Document HF Guidelines for initial UAS Class												▲											
Initial Report on Hazard and Risk-Related Data Collection Efforts												▽											
Report on Communication Security Test Results												▽											
HiTL Sim Assessment Complete														☆									
Integrated Simulation Report														▽									
Flight Evaluations of SA Trajectory Algorithms Complete																▲							
Analysis Results and Recommendations for Integ. Of CNPC and ATC Comm.																▲							
Integrated Flight Test III Flight Report																		▽					
Flight Evaluations of Multiple key UAS Technologies and Concepts Complete																				▲			
Integrated Flight Test IV Flight Report																						▽	
SSI Flight Demonstration II Results																							▽

APG



L1 Program (ISRP)



L2 Project



Hollow symbols are planned. Filled symbols are complete

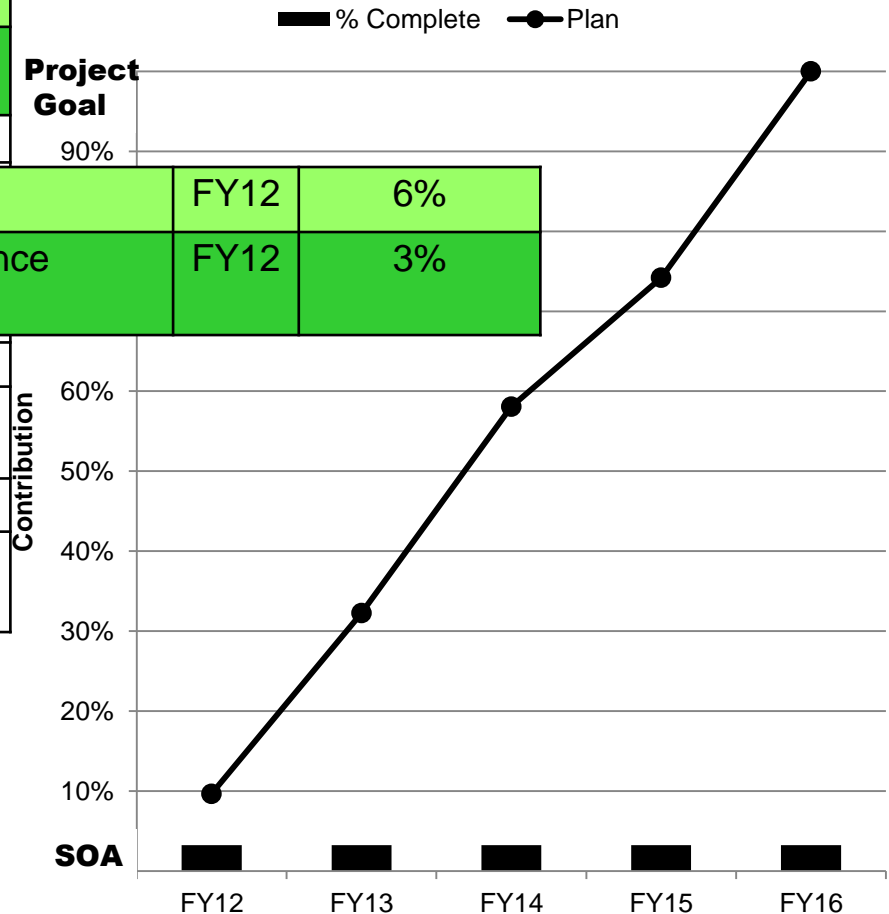




# Airspace Integration Technical Challenge Performance Measure



Technical Milestone/Activity	FY	Contribution
Concept of Integration (SSI)	FY12	6%
Support 2012 World Radio Conference (Comm)	FY12	3%
Fast-time assessment (SSI)	FY13	19%
Candidate frequency band characterization (Comm)	Concept of Integration (SSI)	
HITL simulation (SSI)	Support 2012 World Radio Conference (Comm)	
Integrated-HITL simulation		
Flight Test 3 (SSI)	FY15	10%
Prototype Interface/Candidates II definition (HSI)	FY15	6%
Flight Test 4 (SSI, HSI)	FY16	22%
Initial CNPC system operational capabilities validation (Comm)	FY16	6%

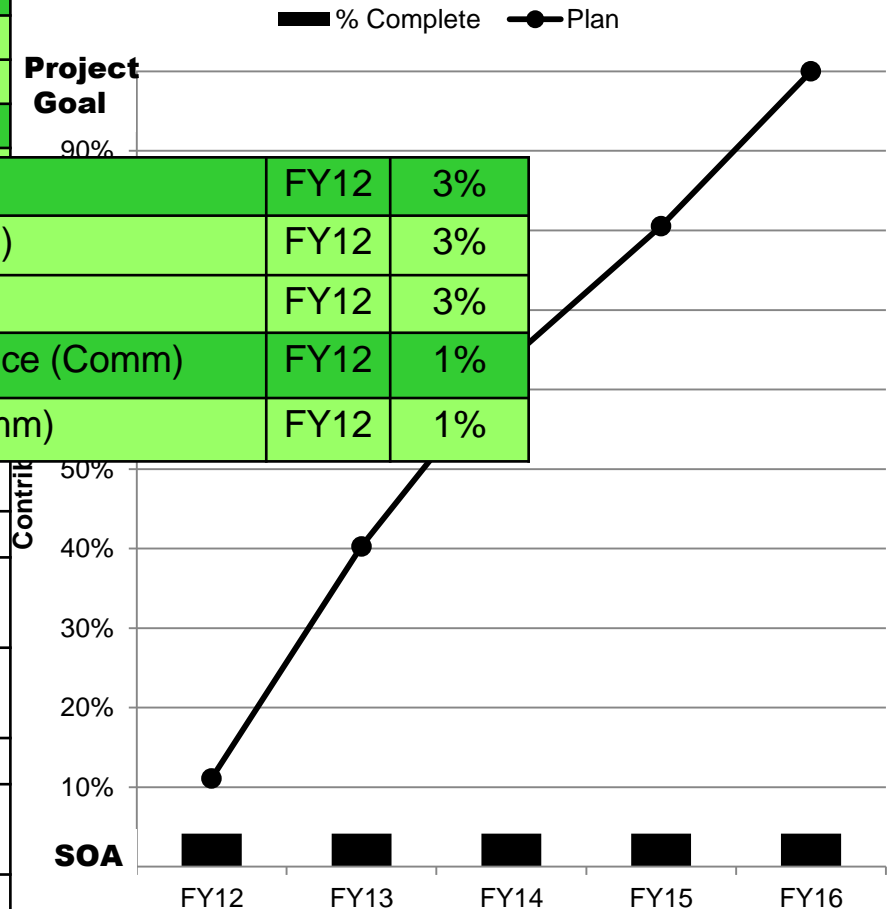


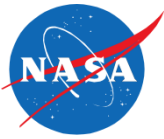


# Standards/Regulations

## Technical Challenge Performance Measure

Technical Milestone/Activity	FY	Contribution
Workshop (HSI)	FY12	3%
GCS information Requirements (HSI)	FY12	3%
Candidate GCS Suite (HSI)	FY12	3%
Support 2012 WRC (Comm)	FY12	1%
CNPC system risk as		
Fast-time assessment		
Class guidelines (HSI)		
CNPC/Spectrum anal		
Risk/Airworthiness an		
Integrated-HITL simul		
CNPC prototype/secu		
development and NAS-wide simulation		
Risk/Airworthiness validation (Cert)	FY14	7%
Flight Test 3 (SSI) and Candidates II definition/HITL simulation (HSI)	FY15	9%
CNPC system security mitigations verification in flight environment (Comm)	FY15	1%
Risk/Airworthiness final analysis (Cert)	FY15	5%
Flight Test 4 (SSI, HSI) and final GCS guidelines (HSI)	FY16	13%
CNPC NAS-wide analysis (Comm)	FY16	6%
Final type design certification criteria report (Cert)	FY16	1%

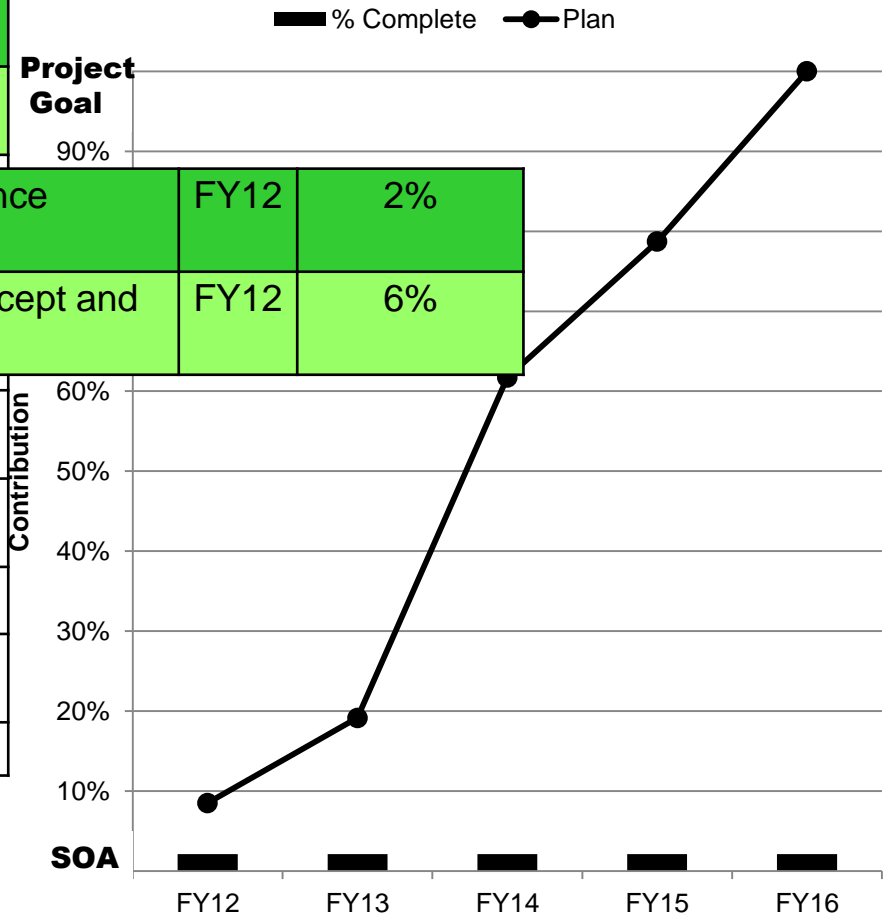




# Relevant Test Environment Technical Challenge Performance Measure



Technical Milestone/Activity	FY	Contribution
Support 2012 World Radio Conference (Comm)	FY12	2%
Integrated-HITL and Flight Test Concept and Objectives development (IT&E)	FY12	6%
LVC-DE development/		
CNPC prototype system development/modification		
CNPC system security development/testing (Comm)		
Integrated-HITL simulation (SSI, HSI, IT&E)	FY14	30%
CNPC system security mitigations verification in flight environment (Comm)	FY15	2%
Flight Test 3 (SSI, IT&E)	FY15	15%
Initial CNPC system operational capabilities validation (Comm)	FY16	4%
Flight Test 4 (SSI, HSI, IT&E)	FY16	17%





# Project Overview

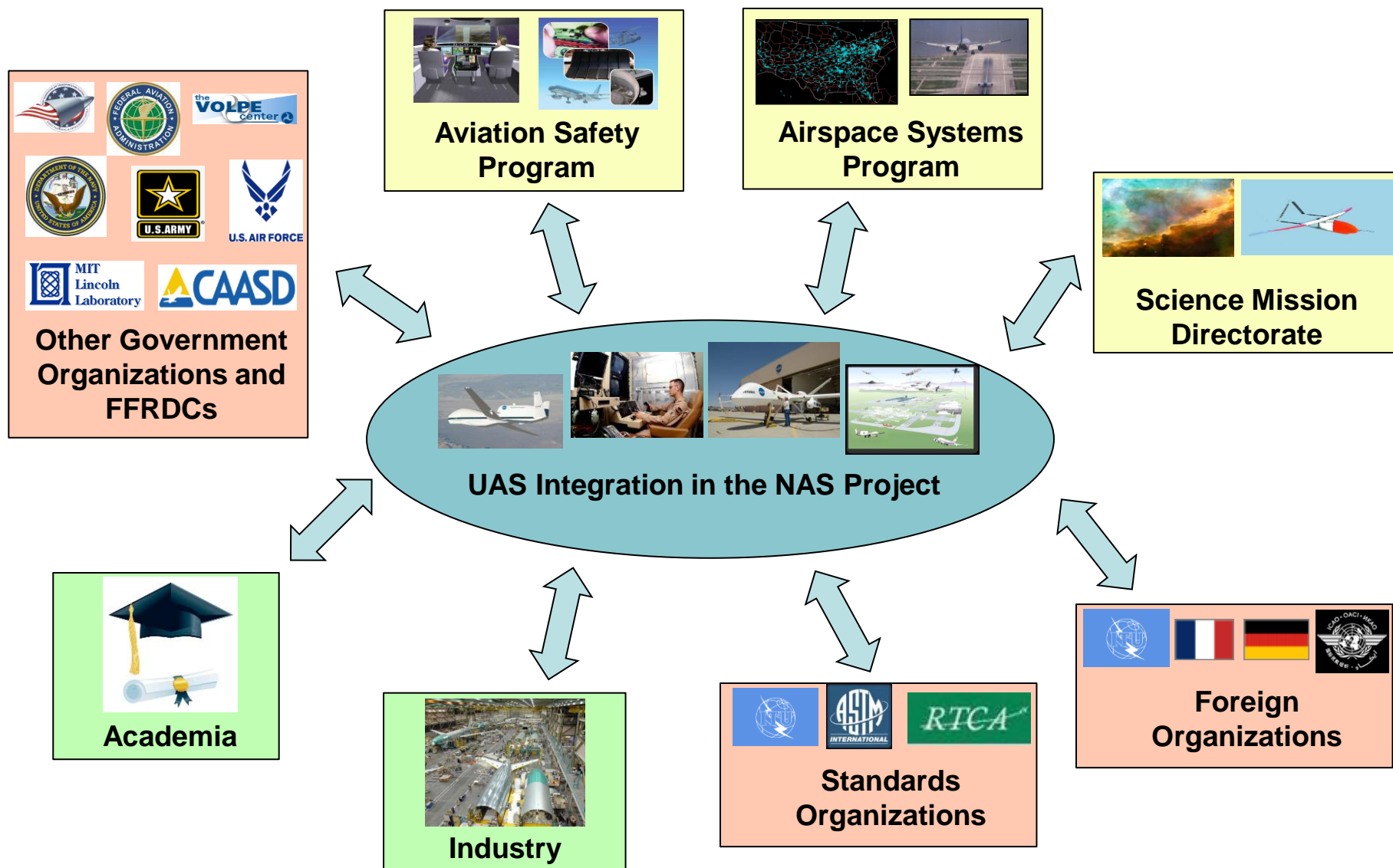


## Changes since the last briefing to the NAC Aeronautics UAS Subcommittee

- Changes in the UAS Community
  - Aviation Rulemaking Committee
  - Establishment of the FAA UAS Integration Office
  - DoD and FAA Legislation (including Test Ranges)



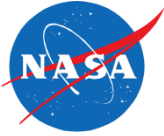
# Partnerships and Collaborations





# Project Outreach and Partnerships

- UAS Executive Committee
  - This committee is supported at very senior levels within the FAA, DoD, DHS and NASA to address the needs of public UAS access to the NAS. NASA has a role as both a provider of technology and a beneficiary of the outputs to enable science missions.
- FAA
  - Direct interactions with relevant FAA organizations is necessary to ensure the Project understands their challenges. Specific collaboration is occurring with:
    - UAS Integration Office
    - Air Traffic Organization
    - NextGen Office
    - FAA Technical Center
    - UAS Aviation Rulemaking Committee
- DoD
  - Current DoD collaborations include:
    - Air Force Research Lab
    - Broad Area Maritime Surveillance Program
    - Pentagon
    - NORTHCOM simulation and testing



# Project Outreach and Partnerships (cont)



- JPDO
  - The JPDO is tasked with defining NextGen. Since UAS must be incorporated into NextGen, this relationship is critical
  - Leverage already occurs with ARMD primarily through the Airspace Systems Program and Aviation Safety Program. The Project will continue to meet routinely with JPDO to synch outputs with the national strategy consistent with NextGen.
- Standards and Regulatory Organizations
  - The FAA relies on standards organizations to bring industry recommendations forward for consideration. Partnering with these organizations is essential to developing the data and technologies necessary for the FAA to approval civil UAS access.
  - Ongoing participation in committees like RTCA Special Committees, American Society for Testing & Materials (ASTM), and the World Radio Conference (WRC)





# Project Outreach and Partnerships (cont)



- Industry
  - NRA Recipients:
    - Boeing, Intelligent Automation, Inc., Honeywell, Logic Evolved Technologies, Inc., SAAB/Sensis Corporation, Modern Technology Solutions Inc.
  - Other Industry Interactions:
    - UtopiaCompression Corporation, Aerovironment, Aerospace Industries of America UAS Subcommittee, General Electric, Northrop Grumman, General Atomics, Mosaic
- Academia
  - NRA Recipients:
    - New Mexico State University, Utah State University, University of Michigan, Embry-Riddle Aeronautical University
  - Cooperative Agreement:
    - CSU - Long Beach
  - Other Academia Interactions:
    - University of North Dakota, Stanford, Cal Poly San Luis Obispo, Brigham Young University, University of Colorado



# Project Outreach and Partnerships (cont)



- International
  - International Telecommunications Union (Working Party 5B)
  - UVS International
  - ICAO through FAA
- Across NASA Programs, Mission Directorates, Centers
  - Airspace Systems
  - Aviation Safety
  - Science Mission Directorate
  - Kennedy Space Center
- Formal Agreements
  - FAA
  - DoD
  - JPDO
  - VOLPE



# Project Outreach and Partnerships (cont)



- Project Annual Meeting
  - Purpose: Present Project to Industry
  - Date: July 31 – August 1
  - Agenda:
    - Briefings by NASA, FAA, DoD, and RTCA
    - Specific technical break out tracks by subproject



# Questions?

*Chuck Johnson (Dryden)*  
*[Chuck.Johnson-1@nasa.gov](mailto:Chuck.Johnson-1@nasa.gov)*



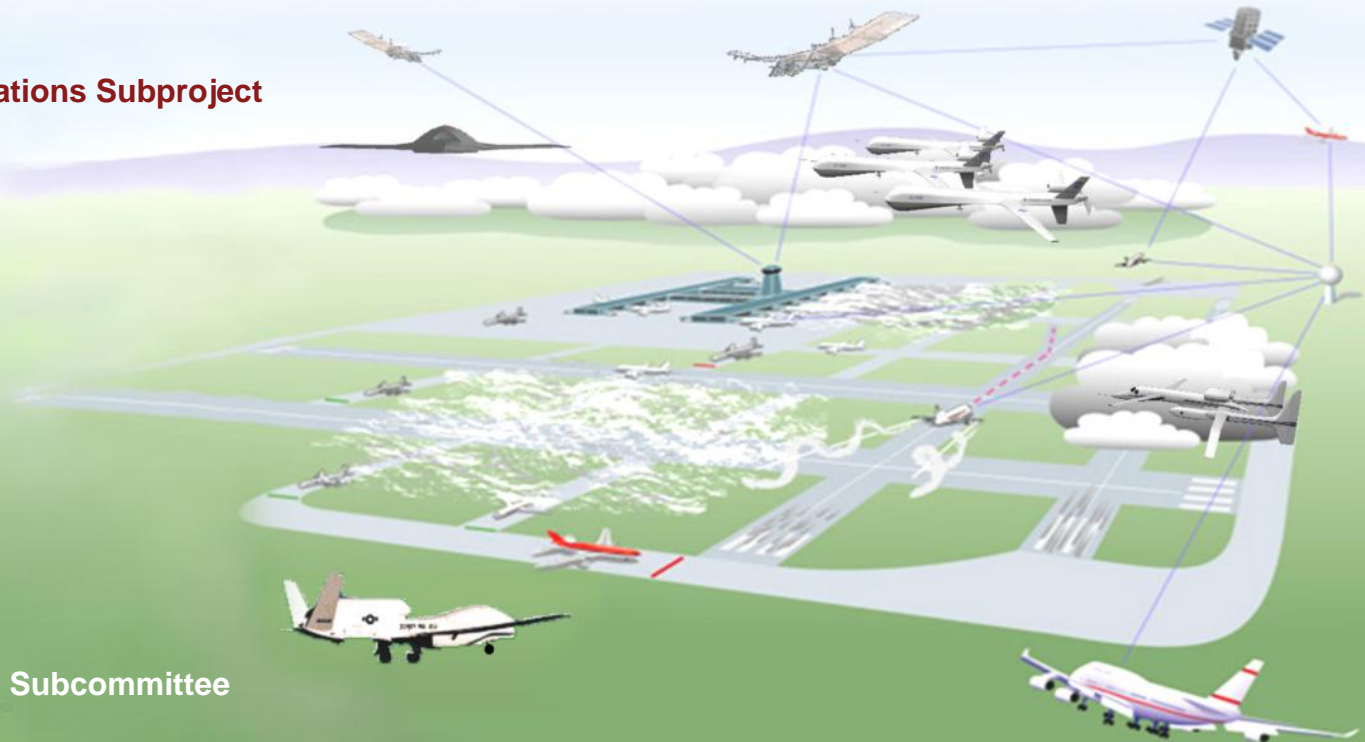
National Aeronautics and Space Administration



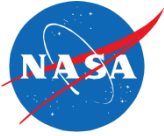
# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

**Presented by: Mr. Jim Griner**

**Project Engineer, Communications Subproject**



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 27, 2012



# Communications Outline

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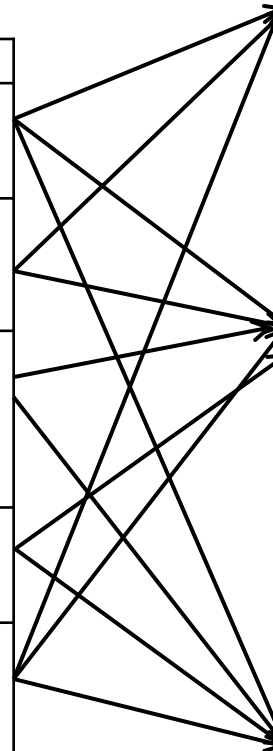


- Project Technical Challenges/Subproject Milestones
- Objectives
- Technical Approach
- Accomplishments
- Linkages to other Subprojects
- Partnerships



# Communications

FY	Technical Activity
FY12	Support 2012 World Radio Conference; CNPC system risk assessment
FY13	Candidate frequency band characterization; CNPC system risk mitigation analysis; CNPC systems model development, all classes
FY14	CNPC prototype system development/modification; CNPC system security mechanisms development/testing; CNPC system NAS wide simulation
FY15	CNPC system security mitigations verification in flight environment
FY16	Initial CNPC system operational capabilities validation; CNPC system air traffic delay/system capacity simulation



## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS

CNPC = Control and Non-Payload Communication





# Communications

**The Communications subproject will seek to address barriers regarding lack of frequency spectrum and data links for civil UAS control communication.**

- **Objectives**

The Communications subproject technical challenge will be met through 4 primary objectives:

1. Develop data and rationale to obtain appropriate frequency spectrum allocations to enable the safe and efficient operation of UAS in the NAS
2. Develop and validate candidate UAS Control and Non-Payload Communication (CNPC) system prototype which complies with proposed international/national regulations, standards, and practices
3. Perform analysis and propose CNPC security recommendations for public and civil UAS operations
4. Perform analysis to support recommendations for integration of CNPC and ATC communications to ensure safe and efficient operation of UAS in the NAS



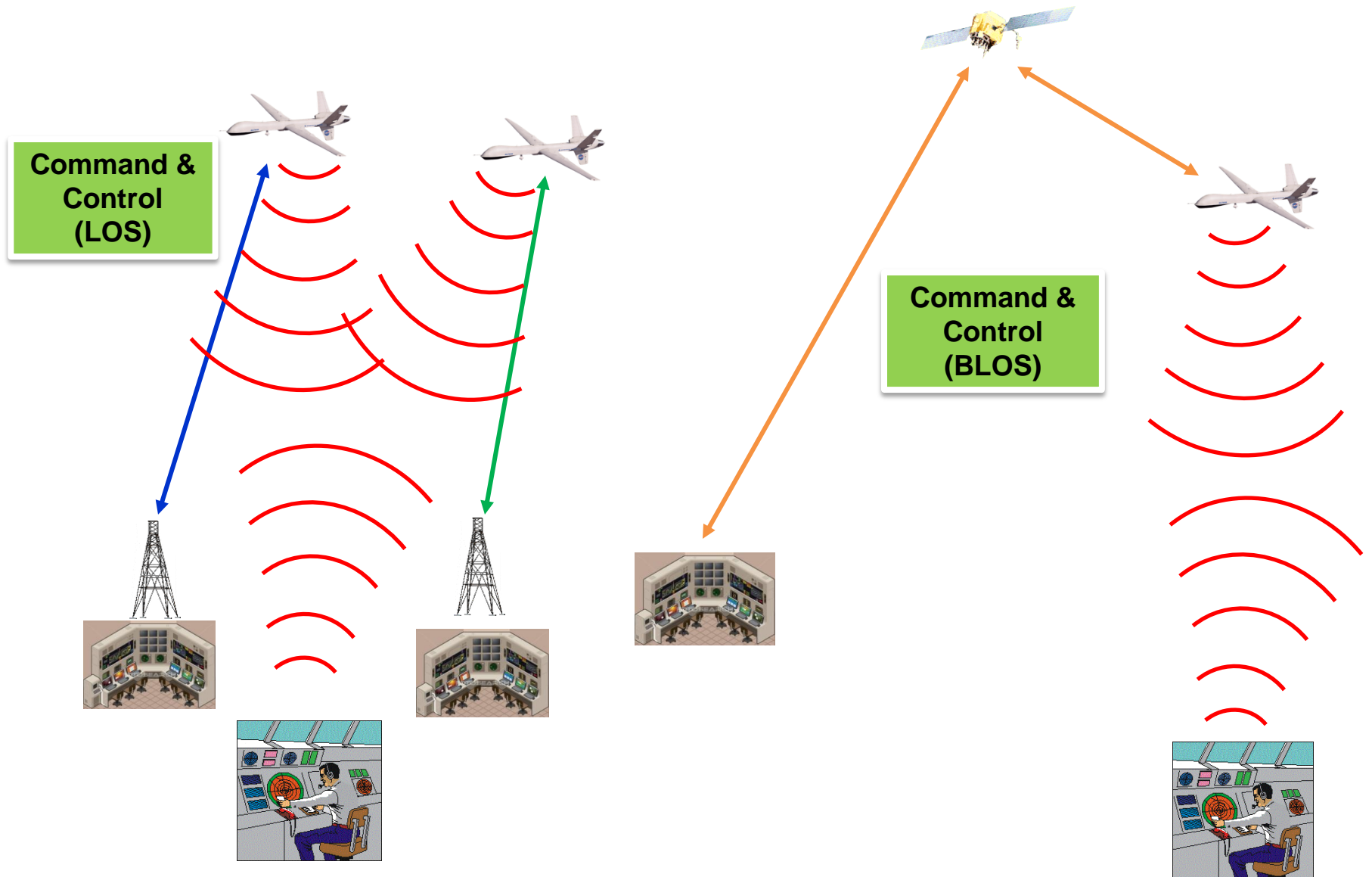
# Communications

## Milestones and Technical Challenge Reduction



- Approach:
  - Perform analysis to support National/International efforts within ICAO and ITU-R Working Party 5B to obtain terrestrial and satellite based spectrum for UAS CNPC systems, in preparation for World Radio Conferences 2012 and 2016
  - Design, develop, and test a prototype communication system under a Cooperative Agreement with an industry partner, to validate proposed RTCA SC-203 CNPC performance standards and to recommend necessary modifications to these standards as a result of laboratory and flight testing in a relevant environment
  - Perform analysis, develop, and test necessary mitigation techniques to risks and vulnerabilities of the CNPC system during the prototype system development, to assure risks and vulnerabilities are mitigated to the required level
  - Develop high fidelity communication system models and perform NAS-wide simulations of the CNPC system, to assure communication system scalability and to minimize impact on aircraft traffic control communication, system delays, capacity, safety, and security

# Current Architecture





# Scope



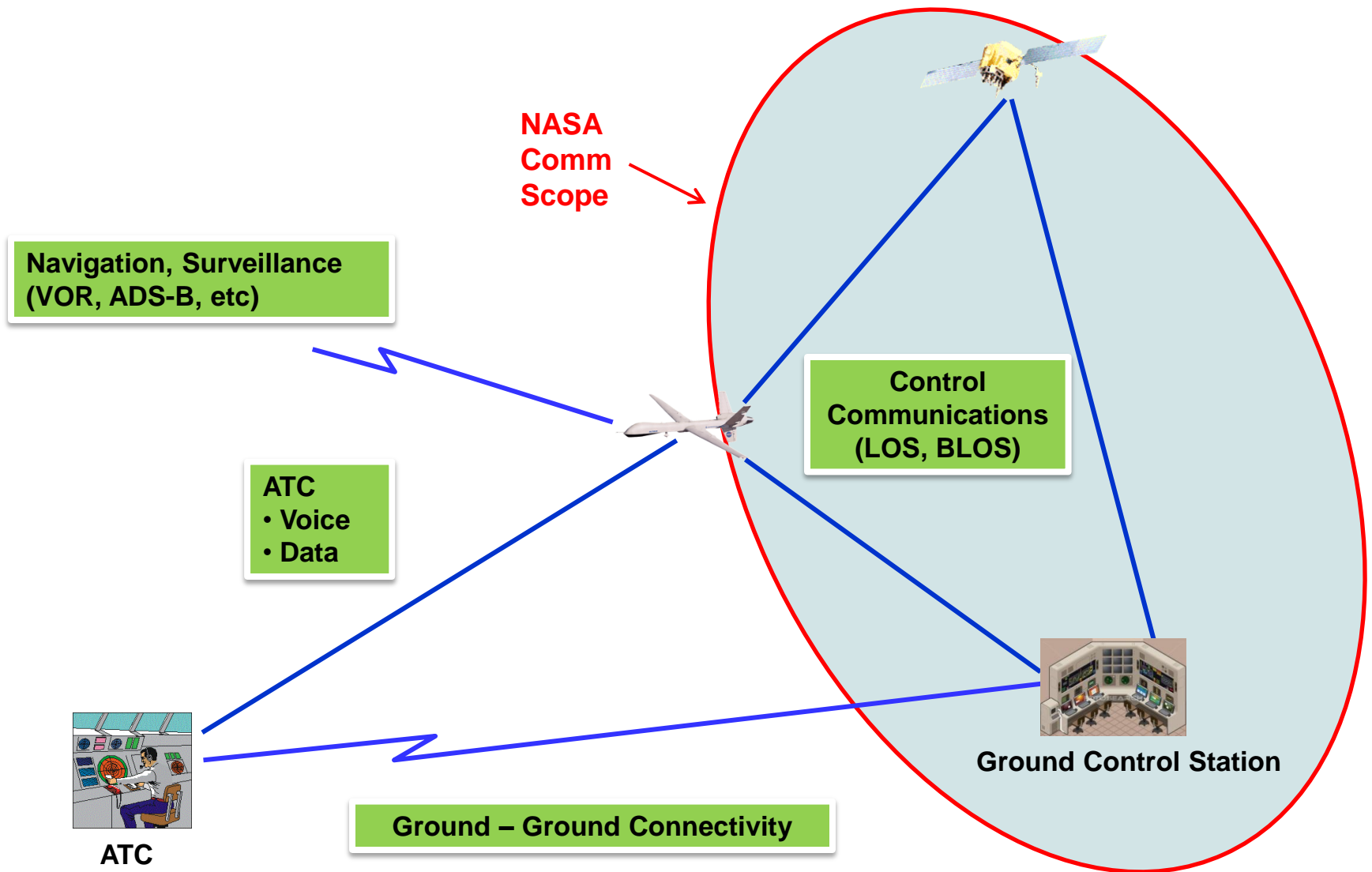
- All UAS Classes
- All Airspace Classes
- Control and Non-Payload Communication (CNPC) Spectrum for both LOS and BLOS connectivity
- CNPC Datalink
- CNPC Security
- CNPC Scalability & ATC Communication Compatibility

## **Not in Scope**

- Changes to existing and planned FAA Communication/Navigation/Surveillance systems
- Onboard Communications & DataBus Technologies
- Miniaturizing Components

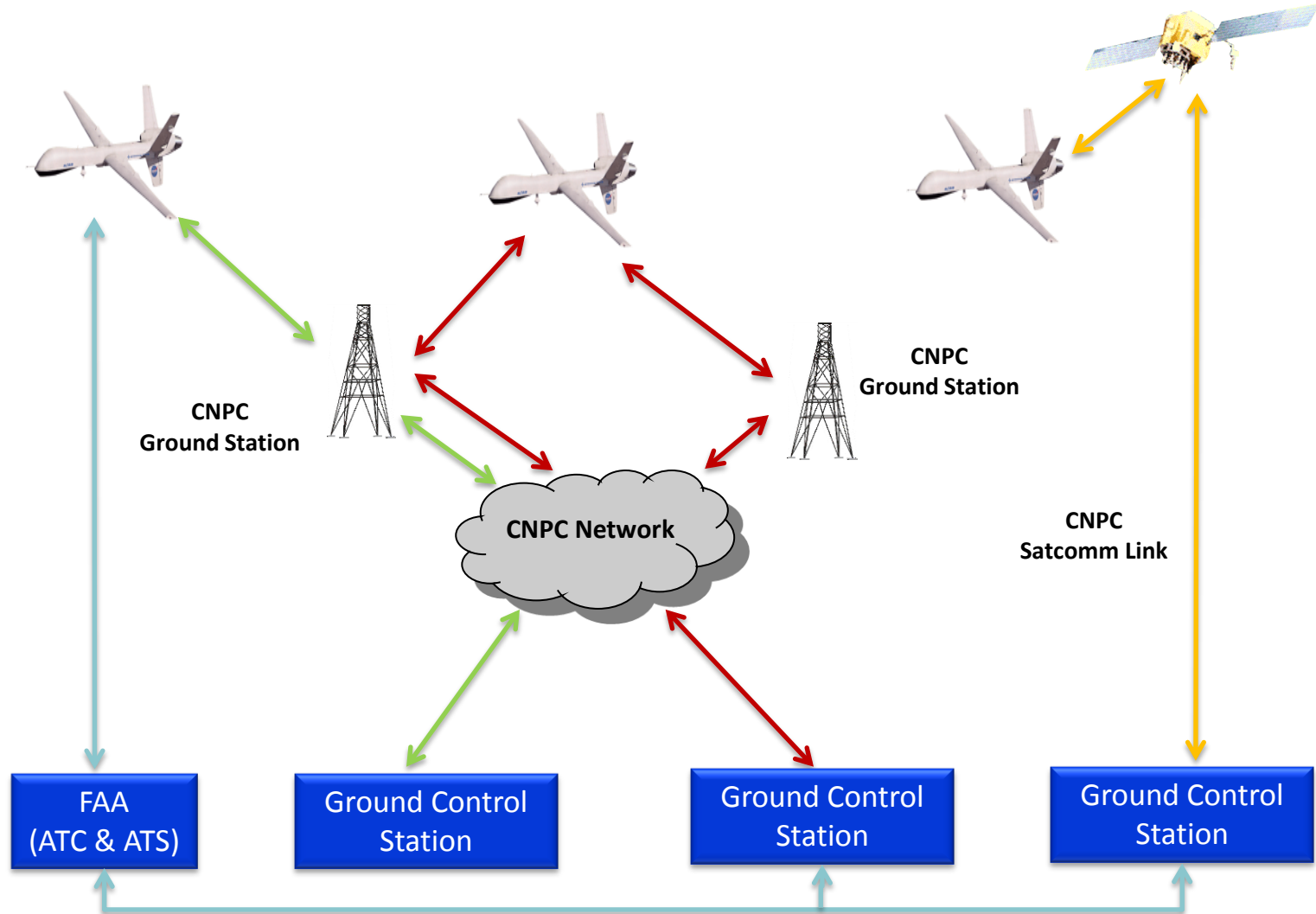


# Generic Single UA Architecture





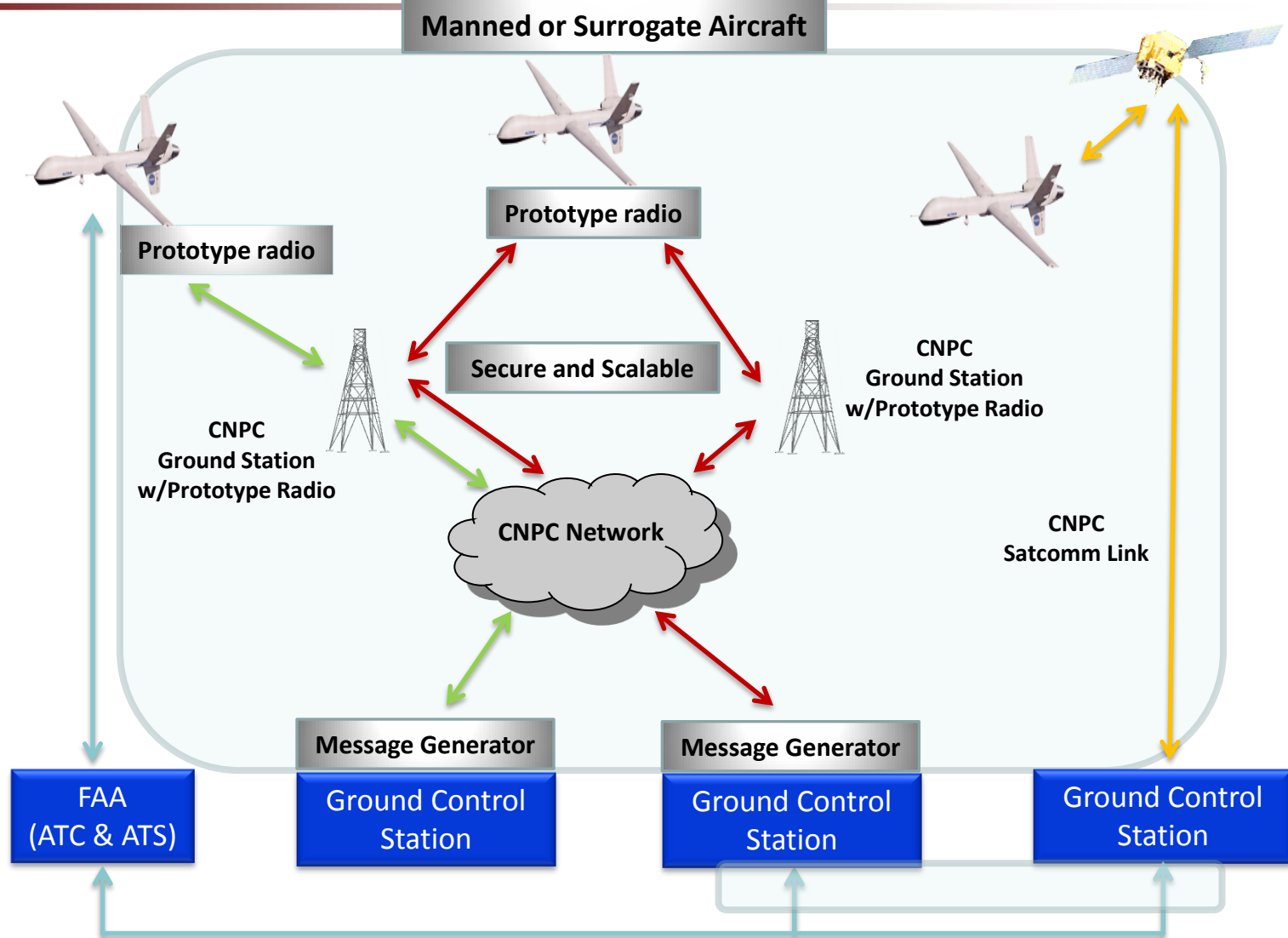
# Civil UAS Communication Architecture



**Possible Future ATC and ATS Ground Connectivity**

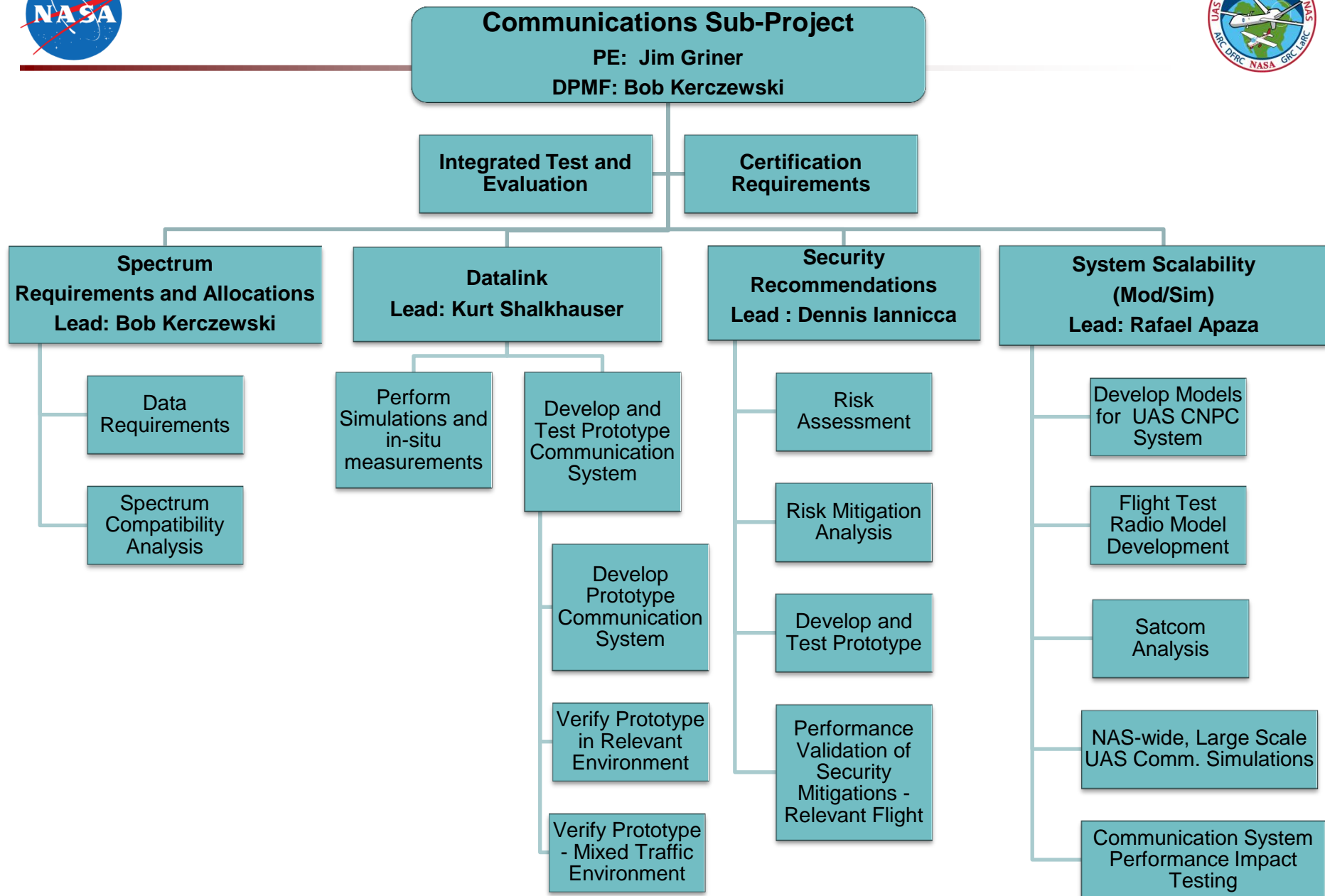


# Communication Subproject Focus



**Possible Future ATC and ATS Ground Connectivity**







# SPECTRUM



# NASA CNPC Spectrum Objectives



- Develop data and rationale to obtain appropriate frequency spectrum allocations to enable the safe and efficient operation of UAS in the NAS
  - Participate and contribute to regulatory/standards organizations developing frequency, safety, security, and performance requirements for UAS CNPC system. Conduct this work in partnership with other US government agencies and commercial entities within national and international spectrum/regulatory bodies.
  - Analyze and develop communications data requirements for use in simulations, radio system design, CNPC system testing, and standardization groups
  - Conduct analysis of proposed UAS control communication spectrum bands, to determine compatibility with in-band and adjacent band users. This information will be used as a basis for spectrum band allocations at WRC-2012 and WRC-2015



# NASA Spectrum Contributions



- Line-of-Sight (LOS) spectrum for UAS CNPC communications
  - Provide technical data to ITU-R Working Party 5B supporting approval of a new AM(R)S spectrum allocation for UAS CNPC to be deliberated at the World Radiocommunications Conference in January-February 2012 (WRC-2012); support the UAS Spectrum Agenda Item (AI 1.3) at WRC-2012 through outreach/education activities.
  - Provide information on UAS CNPC development on an on-going basis to maintain/finalize the technical parameters of the UAS LOS CNPC allocation and support ensuing standards developments.
- Beyond-Line-of-Sight (BLOS) spectrum for UAS CNPC Communications
  - Support establishment of an agenda item for WRC-2015 to consider spectrum allocations in the Fixed Satellite Service for BLOS UAS CNPC.
  - Develop analyses, sharing studies, and compatibility studies, in coordination with RTCA SC-203, to evaluate technical issues involved with the sharing of FSS spectrum for BLOS UAS CNPC.
  - Provide supporting technical data to ITU-R Working Party 5B and ICAO Aeronautical Communications Panel Working Group F supporting the approval of spectrum allocations for BLOS UAS CNPC in the fixed satellite service bands.



# Spectrum Accomplishments Success at WRC-2012

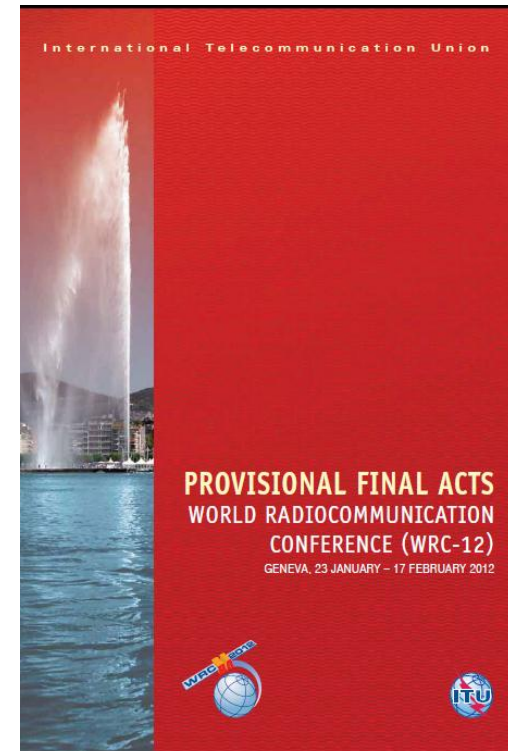


- WRC-2012 approved a new allocation for Aeronautical Mobile (Route) Service (AM(R)S) to support line-of-sight UAS CNPC – 5030-5091 MHz.
- WRC-2012 confirmed the AM(R)S allocation for the 960-1164 MHz (L-Band).

The Communications Sub-Project Provided:

- Data/rationale for Agenda Item 1.3 resulting in the new allocation
- Participation in WRC-2012 preparation activities in ITU-R WP5B, ICAO ACP WG-F, and RTCA SC-203.
- On-site support at WRC-2012 - outreach and education of WRC-2012 delegates to gain the support for Agenda item 1.3.

Allocation to services		
Region 1	Region 2	Region 3
<b>5 000-5 010</b>	AERONAUTICAL MOBILE-SATELLITE (R) ADD 5.B103 AERONAUTICAL RADIONAVIGATION RADIONAVIGATION-SATELLITE (Earth-to-space)	
<b>5 010-5 030</b>	AERONAUTICAL MOBILE-SATELLITE (R) ADD 5.B103 AERONAUTICAL RADIONAVIGATION RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space) 5.328B MOD 5.443B	
<b>5 030-5 091</b>	AERONAUTICAL MOBILE (R) ADD 5.C103	
	AERONAUTICAL MOBILE-SATELLITE (R) ADD 5.D103 AERONAUTICAL RADIONAVIGATION MOD 5.444	
<b>5 091-5 150</b>	AERONAUTICAL MOBILE 5.444B AERONAUTICAL MOBILE-SATELLITE (R) ADD 5.B103 AERONAUTICAL RADIONAVIGATION MOD 5.444 5.444A	





# Spectrum Accomplishments

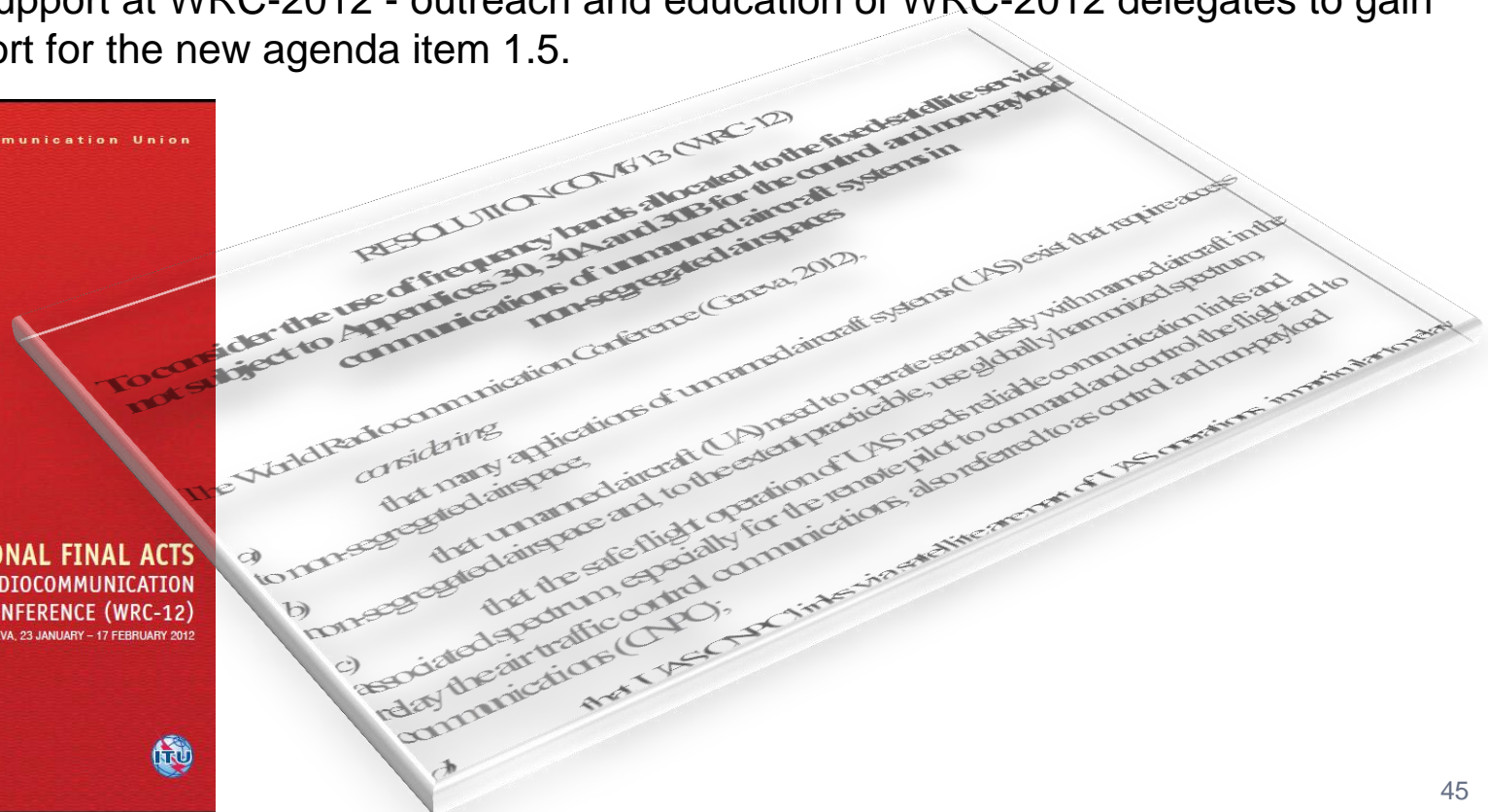
## Spectrum for BLOS CNPC – WRC-2015 AI 1.5



WRC-2012 approved a new agenda item (AI 1.5) for WRC-2015 for spectrum in the Fixed Satellite Service (FSS) bands for UAS CNPC (under Res. COM6/13)

The Communications Sub-Project Provided:

- Participation in WRC-2012 preparation activities in ITU-R WP5B, ICAO ACP WG-F, and RTCA SC-203 to support the new agenda item.
- On-site support at WRC-2012 - outreach and education of WRC-2012 delegates to gain the support for the new agenda item 1.5.







# Spectrum Next Steps



In the coming year, CNPC Spectrum Activities will focus on analyses for BLOS spectrum issues (WRC-2015 AI 1.5) and continued interactions with RTCA SC-203 to develop and coordinate inputs to ITU-R WP5B and ICAO ACP Working Group F

- Preparations for Upcoming ITU-R Meetings (WP5B – November 2012)
  - Coordination with RTCA SC-203 Working Group 2
    - Identify required analyses, spectrum sharing and compatibility studies
    - Identify technical specifications of interfering and victim systems
    - Identify applicable safety margins
  - Initiate compatibility/sharing studies between UAS CNPC and Fixed Service in the 14.0-14.5 GHz band
- Preparations for ICAO Aeronautical Communications Panel Working Group F Meeting (September 2012)
  - Coordinate through RTCA SC-203 inputs for the ICAO Position on WRC-2015 Agenda Item 1.5.
  - Coordinate through RTCA SC-203 inputs on C-Band channelization issue.
  - Develop updated working papers on NASA technology assessment and trade studies results, and updated information paper on L-Band/C-band channel characterization campaign.





# DATALINK



# Datalink Objectives

- Develop and validate candidate UAS safety critical Control and Non-Payload (CNPC) system/subsystem prototype which complies with proposed UAS international/national frequency regulations, ICAO Standards and Recommended Practices, FAA policies/procedures/regulations, and RTCA MASPS/MOPS
  - Development of propagation environment channel models for candidate CNPC spectrum bands
  - Spiral development of prototype CNPC system consisting of both ground and airborne CNPC radios
  - Verify CNPC System prototype in a relevant environment
  - Verify CNPC System prototype performance in a mixed traffic environment



# Data Link Contributions



- CNPC Prototype Radio Trade Study Analysis
  - Analyze portion of latency budget assignable to elements of the controller-pilot-UAS system
  - Analyze ability of CNPC system to meet its latency budget
- Air-Ground Channel Models
  - Develop models of air-ground propagation environment based on channel sounding flight tests, to allow accurate designs for aircraft and ground CNPC communication systems
- Laboratory and Relevant Flight Testing
  - Laboratory testing of CNPC radios and flight testing of end-to-end CNPC system will evaluate CNPC system prototype performance and validation of models
  - NASA, in cooperation with our partner Rockwell, will be building and fielding multiple CNPC ground stations and installing CNPC radios in at least two NASA aircraft. The results from these tests will be used to validate proposed CNPC performance standards or to recommend necessary modifications to these standards before they are published. There may be an opportunity for the FAA to piggyback on the NASA flight tests in order to collect data necessary for their studies.



# Datalink Accomplishments



## NASA – Rockwell Collins Cooperative Agreement

- On Nov 1, 2011, NASA initiated a three-year shared resource cooperative agreement with Rockwell Collins to demonstrate and support the further development of a Unmanned Aircraft CNPC System (\$2M NASA, \$3M Rockwell). Under this agreement we will jointly develop a prototype CNPC system that will provide a basis for validating and verifying proposed CNPC system performance requirements. It will demonstrate an end-to-end CNPC system, including interfacing to a ground based pilot station, transmission of CNPC data to/from more than one ground station, and onboard reception and transmission of CNPC data on more than one UA.
  - Specific tasks for Rockwell Collins include:
    - Identify signal waveforms and access techniques appropriate to meet CNPC requirements within the potential UAS CNPC frequency bands in a manner which efficiently utilizes the spectrum compatibly with other co- and adjacent channel bands services.
    - Develop radios capable of enabling CNPC system testing and validation.
    - Perform relevant testing and validation activities.
  - The radios must operate in proposed UAS radio frequency spectrum
    - 5030 MHz – 5091 MHz (C band)
    - 960 MHz – 977 MHz (L band)
  - Multiple ground stations and multiple aircraft must be supported.



# **CHANNEL SOUNDING FLIGHT TEST PREPARATIONS**



# Background

- At the World Radio Conference 2012, held 23 January - 17 February 2012, two frequency bands were allocated for UAS Control & Non-Payload Communication
  - L- band: 960-1164 MHz
  - C-Band: 5030-5091 MHz
- There are no accurate, validated wideband models exist for the Air-Ground channel in either L or C-bands allocated for UAS. Airframe shadowing models also do not yet exist
- This work intends to perform flight & ground measurements in order to obtain data necessary to develop Air-Ground channel models for UAS, in both the L & C Bands
  - Performing sounding only in 960-977 MHz & 5030-5091 MHz

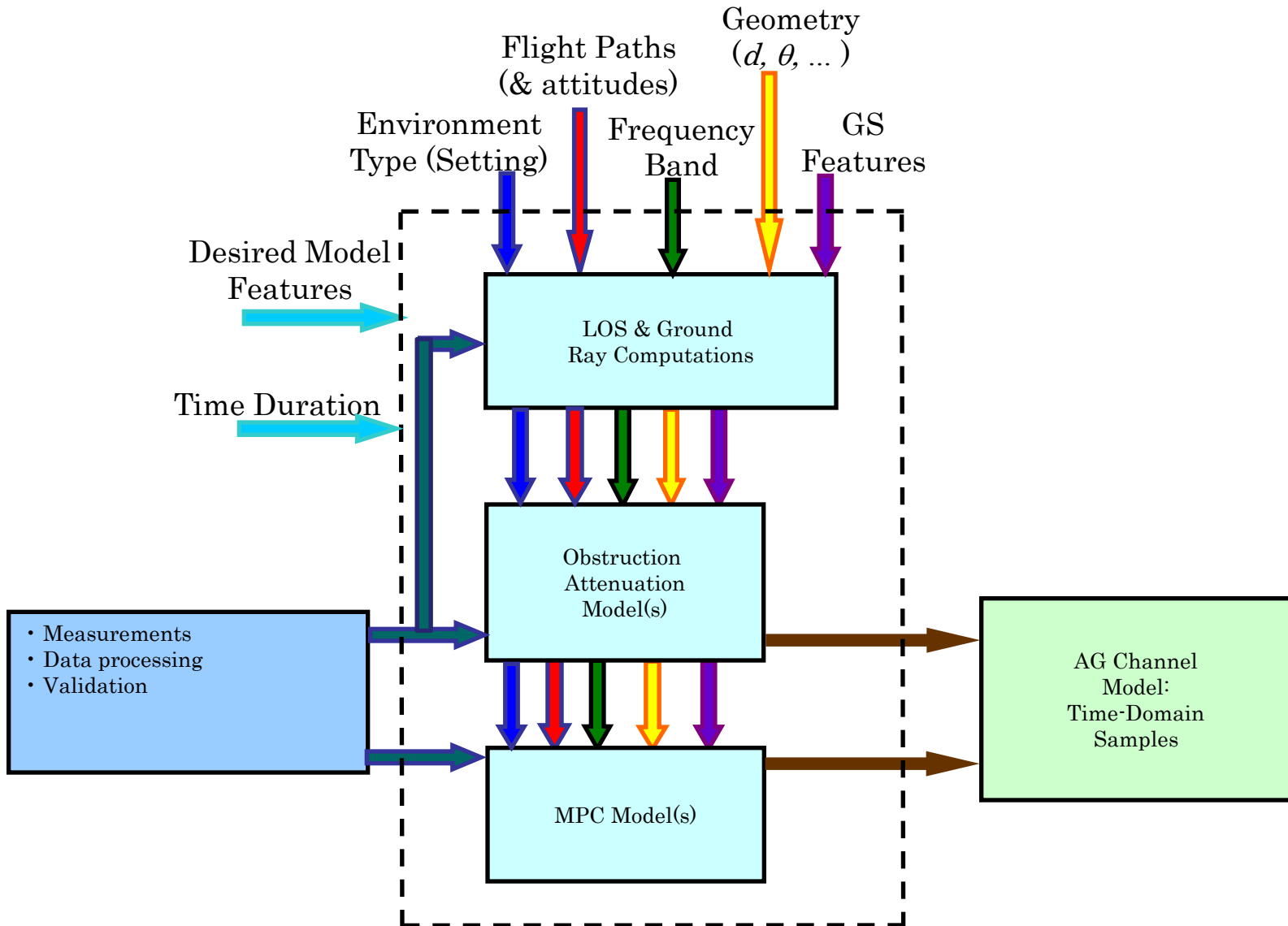


# Channel Sounder

- For the AG measurements, a custom, dual-band channel sounder is being procured by NASA from Berkeley Varitronics Systems (BVS)
  - Measures power delay profiles (PDPs), taken simultaneously from two spatially separated receive antennas in each of the L- and C-bands.
  - PDPs will be taken at a high sample rate (3 kHz) in order to enable measurement of Doppler characteristics [generating 47 Megabytes/second of raw data, for each band]
  - PDPs obtained using the well-known procedure of a stepped correlator receiver that operates on the received direct-sequence spread spectrum signal sent from the companion transmitter
- The BVS sounder will have multiple antenna ports:
  - (i) for the GPS receivers, one port at Tx, one port at Rx;
  - (ii) for two transmitter RF outputs, one for L-band, one for C-band, and;
  - (iii) for four receiver RF inputs, two for the L-band, and two for the C-band.



# AG channel modeling inputs and outputs





# Flight Test Environments



1. Open, over water, GS on shore

2. Flat land

a. urban

b. suburban

c. rural (i.e., plains, some trees)

d. desert

e. forest

3. Hilly land

a. urban

b. suburban

c. rural (i.e., plains, some trees)

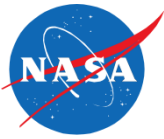
d. desert

e. forest

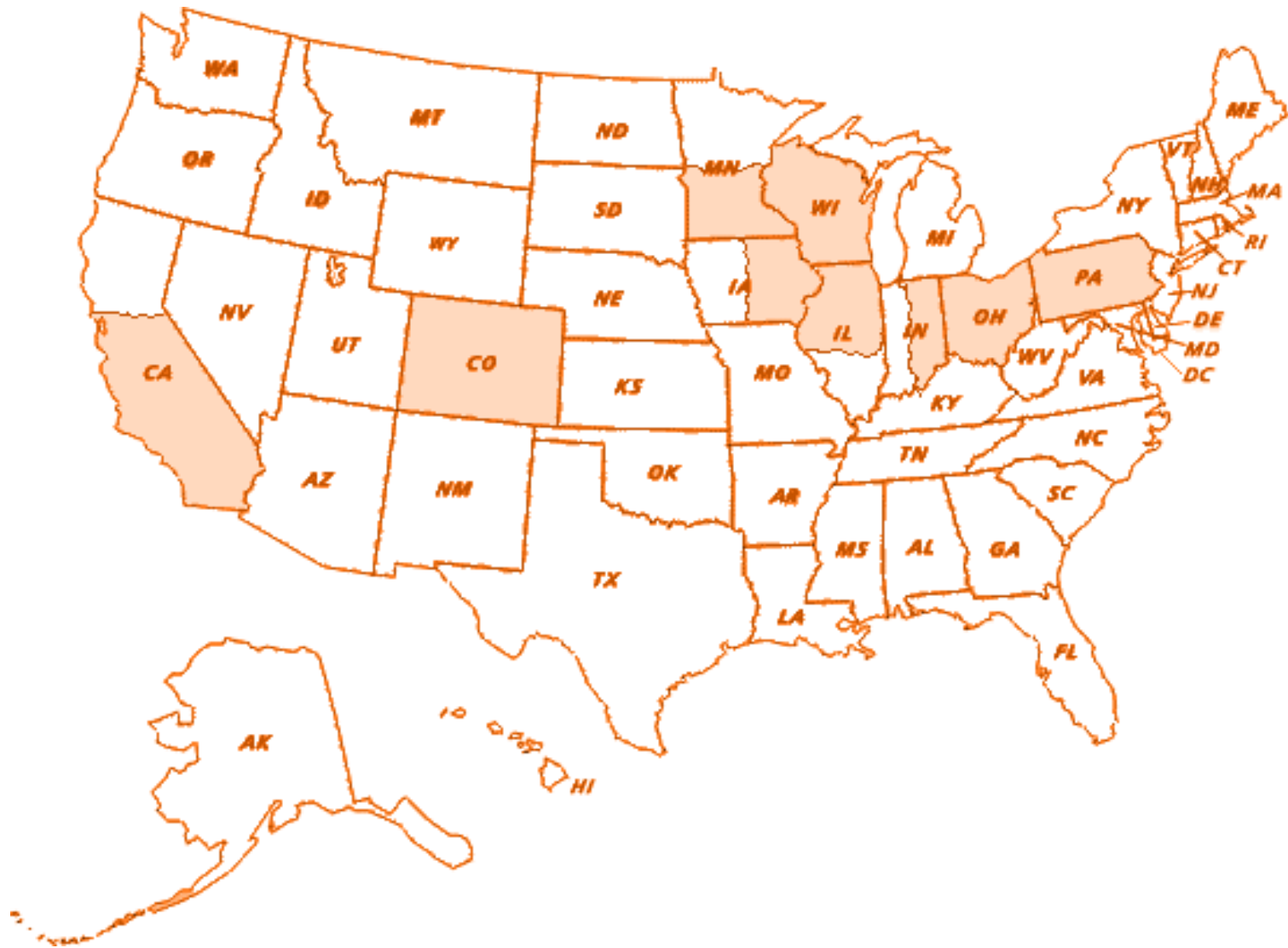
4. Mountainous

a. adjacent to one range

b. among multiple mountains

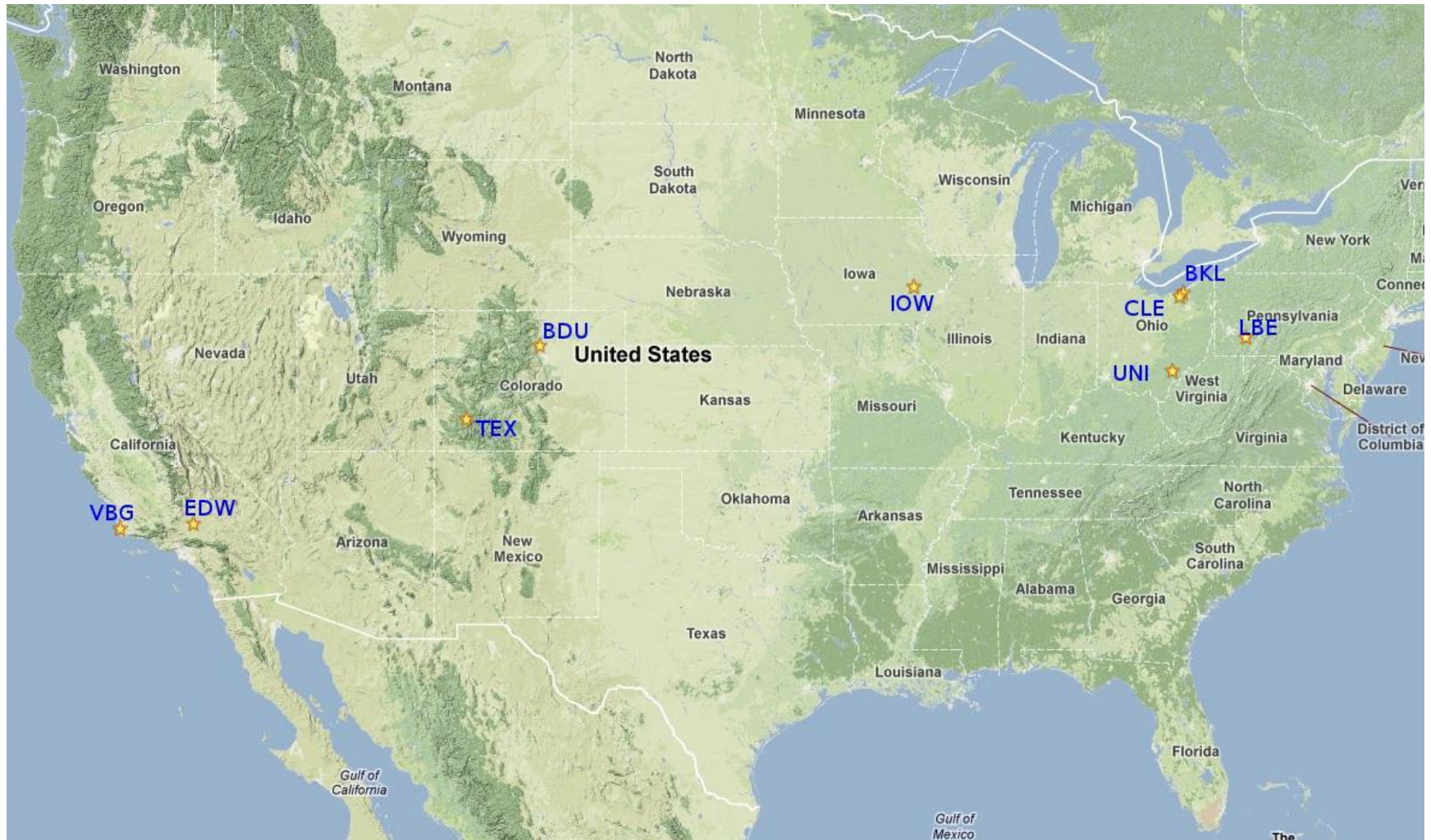


# Spectrum Authorization – Requested Areas





# Proposed Ground Site Test Locations



**VBG – Vandenberg**

**EDW – Edwards Air Force Base**

**BDU – Boulder Municipal**

**TEX – Telluride Regional**

**IOW – Iowa City**

**CLE – Cleveland**

**BKL – Burke Lakefront, Cleveland**

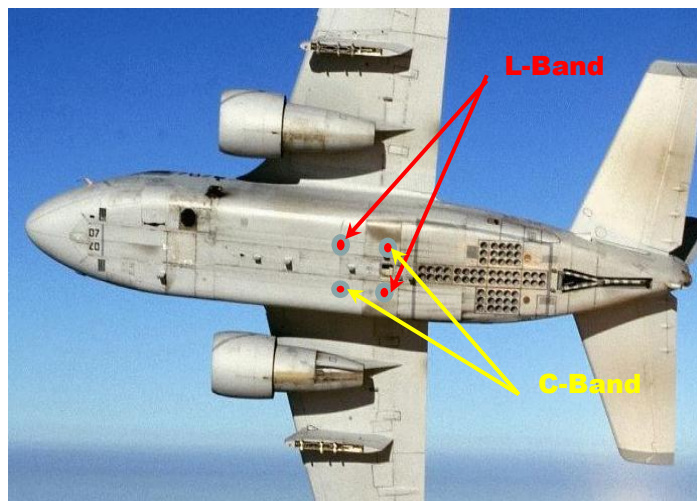
**UNI – Ohio University Airport**

**LBE – Westmoreland County (Arnold Palmer)**



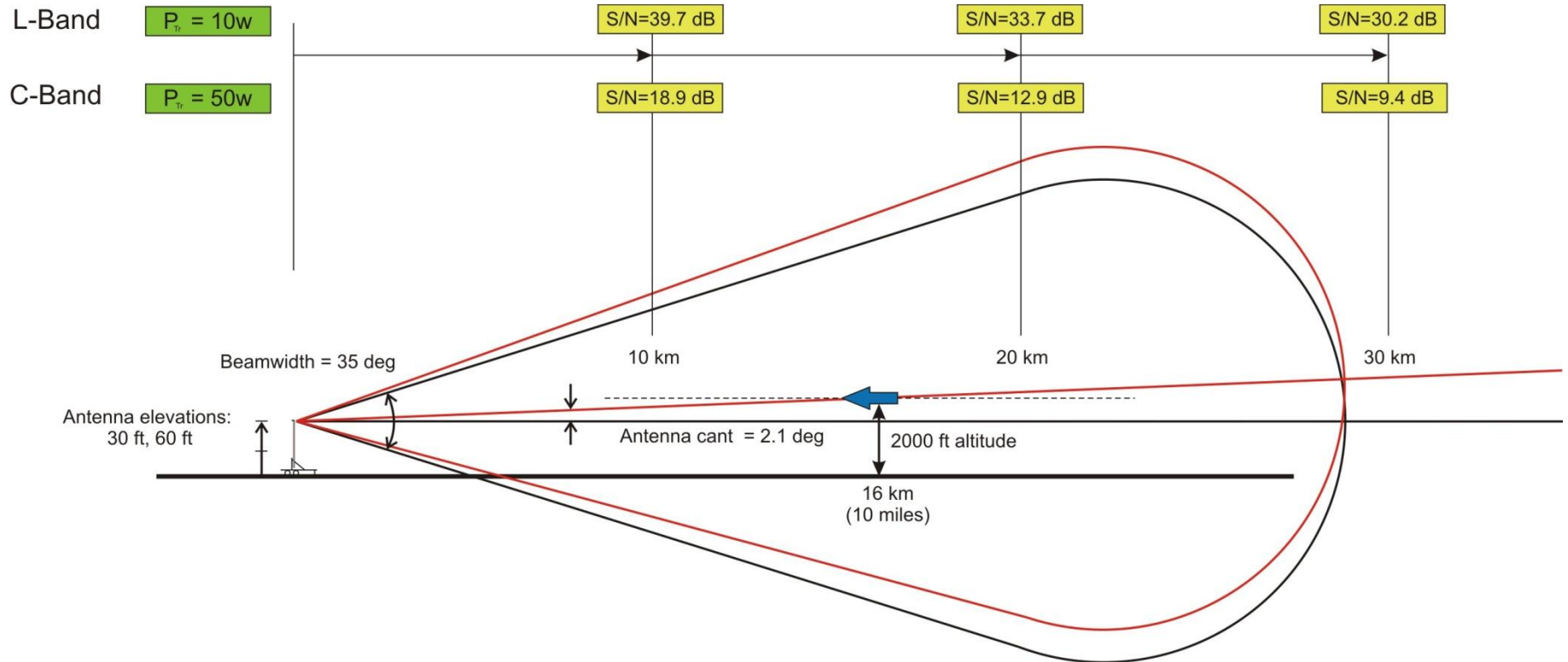


# Aircraft & Ground Station





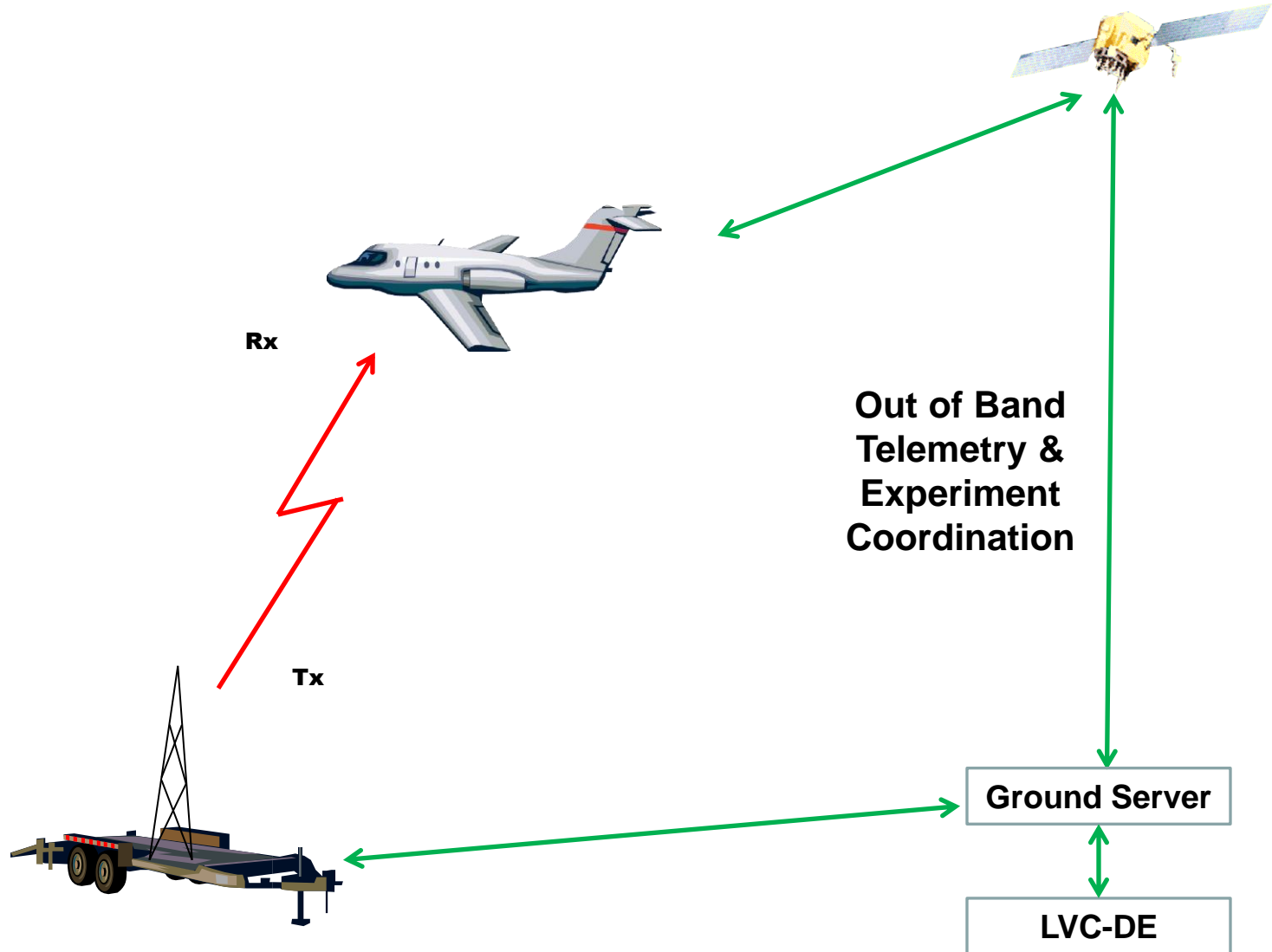
# Flight Path Geometry



- Wide vertical beam allows altitude flexibility while generating ground reflections.
- Transmitting (ground) antenna platform remains in fixed position/tilt during each test (no tracking)
- Sounder system capable of nearly 30 km range with 50w C-band amplifier (minimum S/N = 10 dB)



# Flight Test Architecture



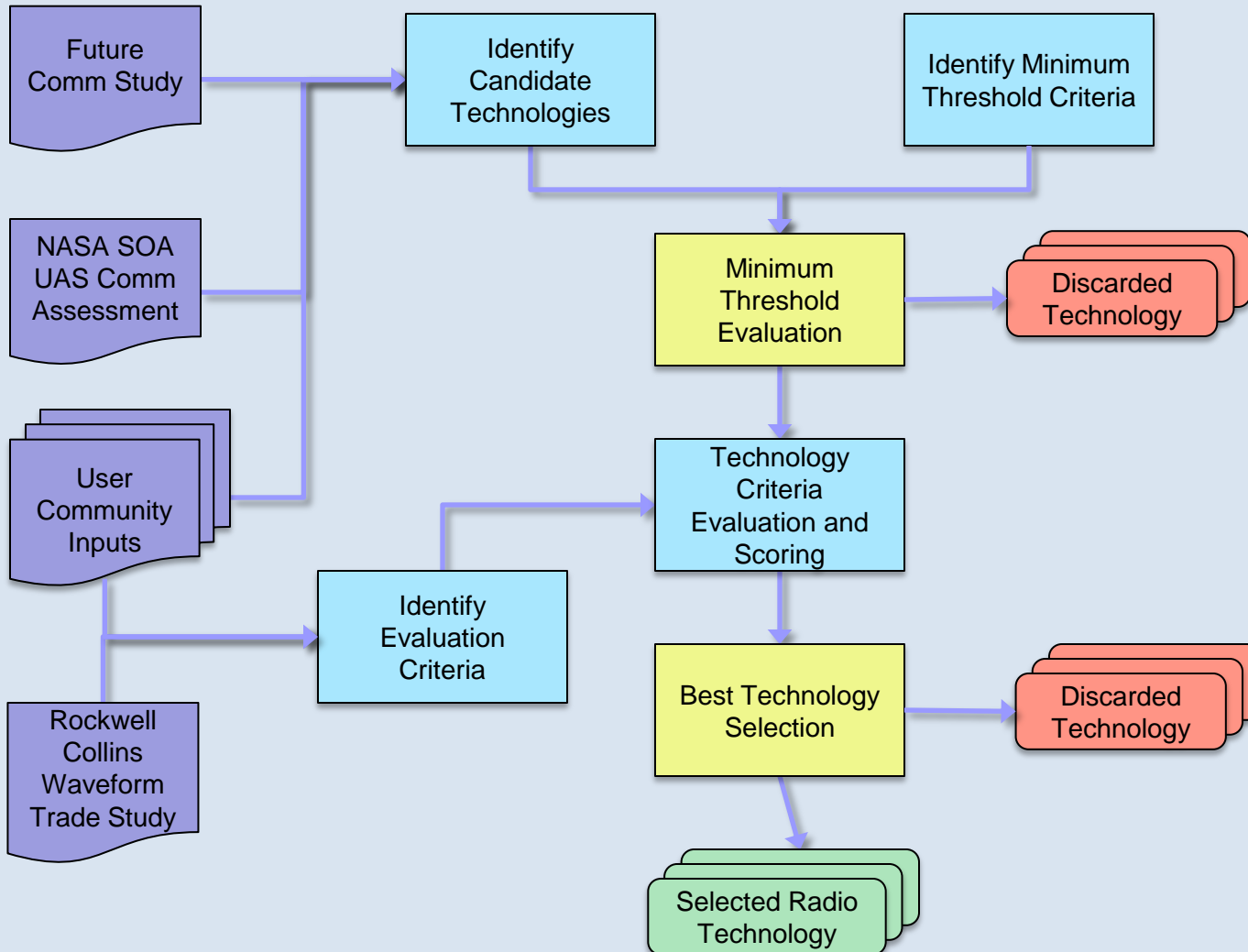




# **PROTOTYPE RADIO WAVEFORM TRADE STUDIES & DATALINK TECHNOLOGY EVALUATIONS**



# Evaluation Methodology



- Identify candidate technologies
- Develop minimum threshold criteria
- Evaluate technologies against minimum threshold
- Define/develop evaluation criteria and scoring methodology
- Integrate additional criteria from RC
- Assess technologies against criteria
- Perform weighted scenario analysis
- Selection of best technology



# Waveform Trade Study

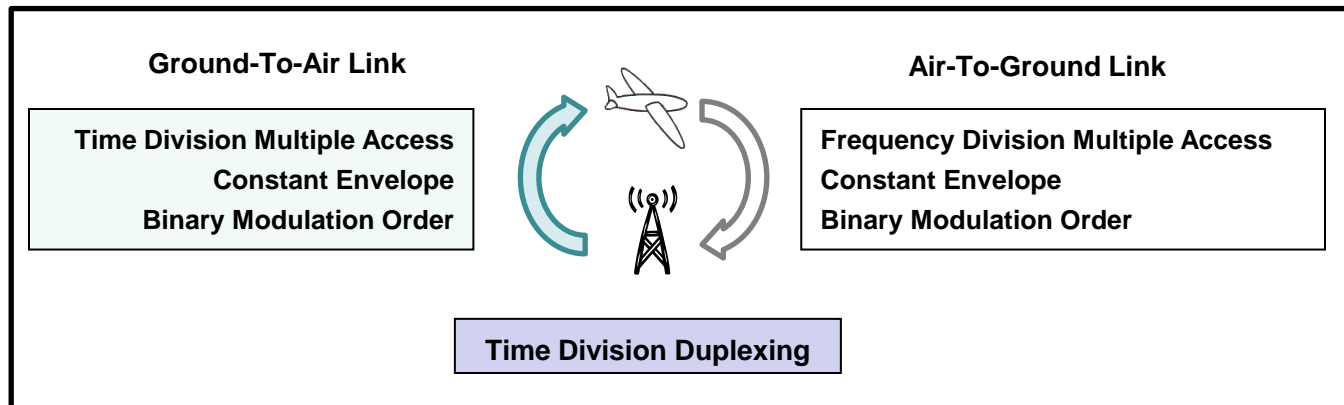
## Seed Requirements

Requirement	Source
Radios must operate in frequency bands 960 – 977 MHz (L band) and 5030 – 5091 (C band)	NASA Contract SOW
L band and C band operations must be independent	NASA Contract SOW
RF link availability for any single link $\geq 99.8\%$ Availability for simultaneous operation of L band and C band $\geq 99.999\%$	RTCA SC-203 CC016
Non-proprietary waveform	NASA Contract SOW
Must operate both air-to-ground and ground-to-air modes	NASA Contract SOW
Aircraft density assumptions Small UAs = 0.000802212 UA/ km <sup>2</sup> Medium UAs = 0.000194327 UA/ km <sup>2</sup> Large UAs = 0.00004375 UA/ km <sup>2</sup>	ITU-R M.2171 P.54
Cell Service Volume Radius = 75 miles (L-Band)	RTCA SC-203 CC016
Maximum number of UAs supported per cell = 20 (basic services) Maximum number of UAs supported per cell = 4 (weather radar) Maximum number of UAs supported per cell = 4 (video)	RTCA SC-203 CC016
Tower height = 100 feet	RC Assumption
Uplink Information Rates (Ground-to-Air) Small UAs = 2424 bps Medium and Large UAs = 6,925 bps	ITU-R M.2171 Table 13
Downlink Information Rates (Air-to-Ground) Small UAs (basic services only) = 4,008 bps Medium and Large UAs (basic services only) = 13,573 bps Medium and Large UAs (basic and weather radar) = 34,133 bps Medium and Large UAs (basic, weather radar and video) = 234,134 bps	ITU-R M.2171 Table 13
Frame rate must support 20 Hz to enable real time control	ITU-R M.2171 Table 23/24
Aviation Safety Link Margin = 6 dB	RTCA SC-203 CC016
Airborne radio transmit power = 10 W	RTCA SC-203 CC016

## Technology Candidates, Criteria, & Scoring

Evaluation Criteria	System Level Factors Addressed	Downlink Multiple Access Candidates		
		CDMA	FDMA	TDMA
Link Margin at Full Capacity	Availability	Unacceptable	Reference	-13 dB for identical PA
Airborne Transmitter Power	SWAP, Cost, Complexity	10 Watts peak	10 Watts peak	200 Watts peak
Multipath Mitigation	Availability, Cost, Complexity	Link margin, spreading, RAKE processing	Link margin	Link margin, adaptive equalization
Synchronization Required	Cost, Complexity	None beyond that required for TDD	None beyond that required for TDD	Tight synchronization for low guard time overhead
Power Control Required	Cost, Complexity	Tight control mitigates near-far problem, 10-20% added complexity	Gross control mitigates near-far problem	Gross control beneficial but not required
Ground Signal Processing Complexity	SWAP, Cost, Complexity	10-20% added complexity	10-20% added complexity	Reference

## Results





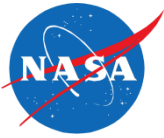
# Datalink Technology Evaluation

## Evaluation Criteria

Category	Criteria
Airground comm	Taxi / Surface / Preflight / Postflight Takeoff / Landing / Terminal En Route
Data Transmission	Addressed capability Repetition rate Command/Control Command/Control and ATC relay Command/Control, ATC relay, and surveillance
Mobility	Handoff Dynamic power control Adaptive modulation rates Active QoS returning
Security	Confidentiality Integrity Availability
Traffic QoS	Traffic cross-carrier distribution Traffic priority Traffic classes Traffic reliability/ARQ Dynamic bandwidth allocation RF statistics reporting Technology Readiness Level
Certification / complexity	Certification Risk Robustness Determinism Link Layer Compatibility
Waveform	Duplexing (TDD/FDD) Uplink multiplexing Downlink multiplexing Uplink modulation Downlink modulation

## Scoring

Category	Criteria																				
		TDMA (GSM)	CDMA (IS-95A)	CDMA (IS-95B)	GSM/GPRS/EDGE	CDMA2000	EV-DO	W-CDMA	TD-SCDMA	CDMA2000 1X RTT	EV-DO	IS-95A	IS-95B	IS-95C	IS-95D	IS-95E	IS-95F	IS-95G	IS-95H	IS-95I	IS-95J
Airground comm	Taxi / Surface / Preflight / Postflight																				
	Takeoff / Landing / Terminal																				
	En Route																				
Data Transmission	Addressed capability																				
	Repetition rate																				
	Command/Control (C&C)																				
	C&C + ATC																				
Mobility	C&C + ATC + Surveillance																				
	Handoff																				
	Dynamic power control																				
	Adaptive modulation rates																				
Security	Active QoS returning																				
	Confidentiality																				
	Integrity																				
	Availability																				
Traffic QoS	Traffic cross-carrier distribution																				
	Traffic priority																				
	Traffic classes																				
	Traffic reliability/QoS																				
Certification / complexity	Dynamic bandwidth allocation																				
	RF statistics reporting																				
	TSL																				
	Certification risk																				
Waveform	Robustness																				
	Determinism																				
	Link layer compatibility																				
	Duplexing																				
Waveform	Forward Link multiplexing																				
	Reverse Link multiplexing																				
	Forward Link modulation																				
	Reverse Link modulation																				



# Datalink Next Steps



- Propagation flight tests will be conducted beginning August, 2012 and conclude December, 2012. Analysis and resulting channel models will be used during development of prototype CNPC radios and will complete the RTCA SC-203 link availability documentation.
- Complete definition of NASA/Rockwell system interfaces. Proceed toward prototype radio PDR (August, 2012), CDR (October, 2012), and Gen 1 radio delivery (February 2013).
- Develop ground and aircraft radio interfaces, data messaging, and test environment, leading to initial system testing during Flight Test #2 (May 2013)
- Continue coordinating with IT&E sub-project on connection to LVC-DE, for testing initial capability during the propagation flight test campaign, leading to full integration during Flight Test #2.
- Continue coordination with SSI sub-project on interfaces to and data requirements of their algorithms, leading to Flight Test #3.
- Continue coordination with HSI sub-project on interfaces to and data requirements of their ground control station, leading to Flight Test #3.



# SECURITY



# Security Objectives



- Develop and Validate Candidate Security Requirements and Standards for UAS CNPC Compliant with Appropriate Regulations.
  - Risk Assessment of a Generic UAS CNPC System – Leverage NIST and FAA SCAP processes to develop documentation.
  - Risk Mitigation Strategy of a Generic UAS CNPC System – Leverage NIST and FAA SCAP processes to develop documentation.
  - Prototype and Test Proposed CNPC Security System(s) in Lab Environment for Performance and Compliance – Create and vet test plan with industry and FAA guidance. Conduct tests to measure effectiveness and report on mitigation components.
  - Prototype and Test Proposed CNPC Security System(s) in Relevant Flight Environment for Performance and Compliance – Create and vet test plan with industry and FAA guidance. Conduct tests to measure effectiveness and report on CNPC system mitigation strategy as well as operational functionality in a flight-test environment.



# Security Contributions



- Vulnerability/Threat Analysis of Generic CNPC System
  - Create representative CNPC system architecture
  - Draft system categorization analysis
  - Document threat and vulnerability list
- Risk Assessment of Generic CNPC System
  - Quantify threats and vulnerabilities to determine risks to CNPC System
  - Document Risk Assessment
  - Study countermeasures and controls
  - Create Risk Mitigation Strategy
- Lab and Relevant Flight Testing
  - Conduct functional testing of security mechanisms
  - Examine performance of security features in CNPC System





# Security Accomplishments



- Create representative generic CNPC system architectures
  - Developed direct CNPC Baseline Architecture
  - Developed networked CNPC Baseline Architecture
- Draft CNPC security categorization document (FIPS Pub 199)
  - Developed security categorizations for telecommand, telemetry, NAVAIDS data, ATC voice relay, ATS data relay, target tracking data, airborne weather radar download data, and non-payload video downlink data
- Document Threat and Vulnerability List (NIST SP 800-30)
  - Created threat list based on NIST and FAA publications
  - Created vulnerability list based on NIST and FAA publications
- Researched numerous documents dating back to the Access 5 project as well as collaborated with key stakeholders including the FAA and RTCA to define baseline security objectives
- Developing a test bed capable of simulating and vetting the security mechanisms in a networked CNPC environment.



# Security – Next Steps



- Complete Risk Analysis
  - Determine impact and likelihood of identified risks
  - Risk determination and control recommendation (NIST SP 800-53)
  - Create risk assessment report
- Risk Mitigation Analysis
  - Evaluate recommended control options
  - Select controls and update architectures
  - Create risk mitigation report
- Develop and Test Prototype
  - Develop air/ground security prototype
  - Integrate air/ground security prototype in lab environment
  - Develop communication security test plan
  - Perform lab testing and analyze test results
- Performance Validation of Security Mitigations - Relevant Flight Environment

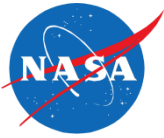


# **SYSTEM SCALABILITY (MODELING & SIMULATION)**



# Modeling & Simulation Objectives

- Perform analysis to support recommendations for integration of safety critical CNPC system and ATC communications to ensure safe and efficient operation of UAS in the NAS
  - Prototype Flight Test Radio Model Validation and Regional Simulations
  - NAS-wide UAS LOS/BLOS CNPC System Simulations with Interim (low-medium fidelity) CNPC link, Communications Models
  - NAS-wide UAS LOS/BLOS CNPC System Simulations with high-fidelity, CNPC link Communications Models
  - Large-scale simulations to evaluate UAS/UAS Comm. impact on ATC operations and on Delays/Capacity/Safety/Security of the NAS
    - Define/perform large scale simulations to evaluate NAS/ATC operations with varying architectures and CNPC Radio models. The evaluation of these simulations will focus on NAS and NAS ATM operational impacts for these varied configurations.



# Modeling & Simulation Plan Elements



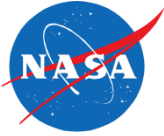
- Models for UAS CNPC Systems
  - Supports technology assessment for selection of CNPC radio technology
  - Develops CNPC system models for analysis of test results
  - Develop high fidelity models for GRC regional and large scale simulations
  - Define UAS communication system parameters for use by ARC, LaRC, DFRC human systems integration, separation assurance, and integrated test/evaluation activities
  - Develop simulations for satellite communications technologies for BLOS UAS CNPC systems supporting UAS spectrum requirements for WRC 2016
- NAS-Wide Communications Performance Test
  - Simulations to assess performance of candidate UAS CNPC Systems in meeting NAS-wide UAS Integration requirements
    - Communications parametric performance
    - Communications capacity and scalability
    - Ability to support UAS in the NAS Con Ops
- Communications System Performance Impact
  - Large scale simulations to assess impact of CNPC system on total NAS performance
    - Assess impact on air traffic control communications
    - Impact on NAS performance – system delays, capacity, safety, security



# Modeling & Simulation Contributions



- Provide results of CNPC radio and system simulations as well as elements of the CNPC models
  - NASA will focus on modeling and simulation of CNPC radio performance and the end-to-end CNPC system performance
  - Will include development of models of air-ground propagation environment based on channel sounding flight tests
- Provide results from large-scale simulations, showing impact of UAS CNPC system on airspace capacity/delays
  - NASA simulations will evaluate NAS performance with integrated UAS, focusing on CNPC system impact
  - NASA simulations model compatibility of UAS CNPC systems with ATC communications and ATM performance
- UAS Comm. System Architecture evaluations and recommendations
  - Air ground architecture evaluations
  - Ground-ground architecture evaluations
- Spectrum performance evaluation and optimization
  - Service volume definition
  - Frequency reuse approach and planning



# Modeling & Simulation Accomplishments



- Performed Data Link Technology Screening
  - Evaluation of latest technologies for applicability within GRC FT Radio
  - Down-selected primary technology for integration with Rockwell Collins radio platform (802.16)
  - Defined the integration approach/methodology for Datalink technology to GRC CNPC radio
  - Defined candidate radio technologies for 3 models to be used in mod/sim evaluations (802.16 + two next best candidates)
- Completed communications architecture evaluation.
  - Assessed the SC-203, IP 005 candidate Comm system Architectures
  - Provided down-select of two architectures for UAS Comm system Large-scale simulations development (Relay Option 4 and Non-relay Option 4)
- Completed evaluation of CNPC data link elements



# Modeling & Simulation Accomplishments (cont.)



- Simulation tool integration, interoperability configuration and testing
  - Evaluated and developed ACES – OPNET interface approach
  - Evaluated and procured RTI tool to interface OPNET and ACES
  - Developed simulation tools architecture and interoperability test plan
  - Identified and tested simulation platform operating system
  - Completed ACES computer configuration and software build
- Large-Scale simulation development
  - Developed initial draft of ATC-PIC message sequence diagrams
- Flight Test Radio Development
  - Initiated collection of know requirements for Flight Test Radio model development

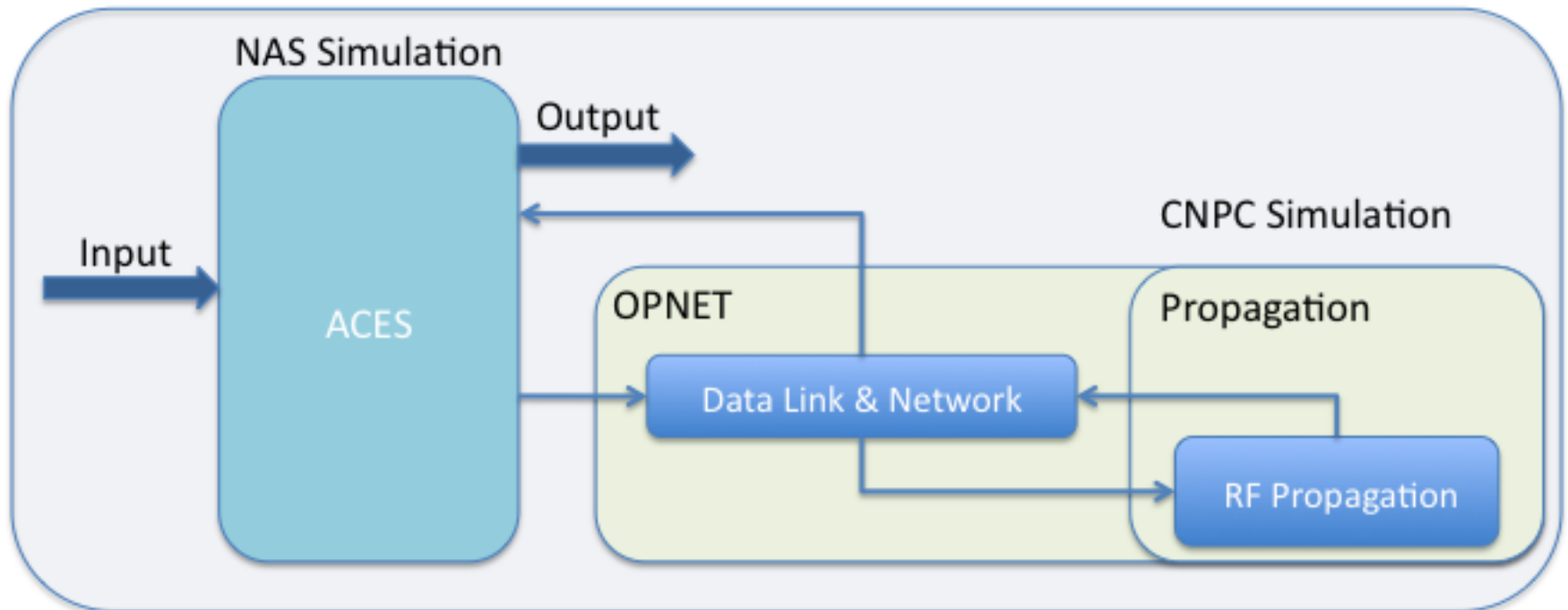




# Modeling Platform Integration



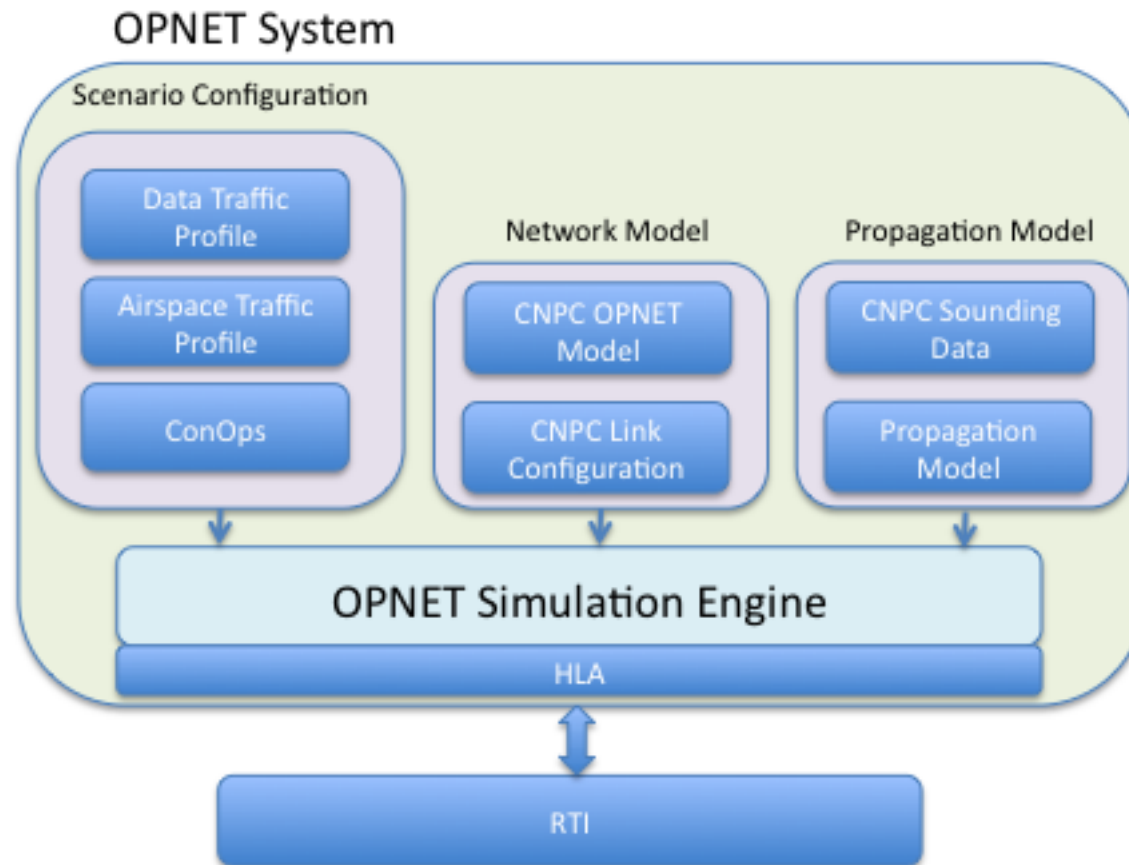
## NAS Wide Simulation



Operating System: Linux – Ubuntu  
Run Time Infrastructure (RTI): MAK



# OPNET Configuration





# Modeling & Simulation Next Steps



- Flight Test Radio Model Development
  - Initial model architecture development (802.16 datalink radio model)
  - Physical and MAC layer development
- Complete full ACES-OPNET interoperability testing
- ACES-OPNET wireframe simulation development
  - Initial ACES and Opnet model/components design and development
  - Complete ATC/PIC and CNPC link data/message set development
  - Integration of basic models for wireframe simulations
  - Wireframe simulations testing and implementation

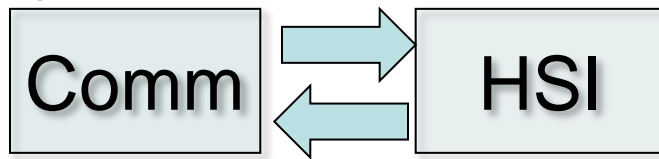
Wireframe simulations will test the ACES-OpNet simulation environment, architecture operation for message flow through the simulated communication system. Basic models will represent model components that will be matured in the models development process leading to Interim (Low-med fidelity) models for initial simulations.



# Linkages to other Subprojects

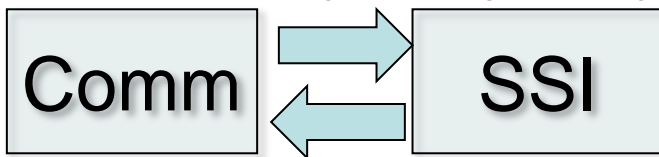


- Communication System Performance Parameters (statistical model)
- Prototype CNPC system for integrated flight tests



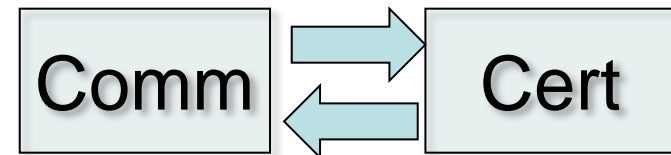
- GCS Information requirements
- GCS for integrated flight testing

- Communication System Performance Parameters (statistical model)
- Prototype CNPC system for integrated flight tests
- Platform for SA algorithm flight testing



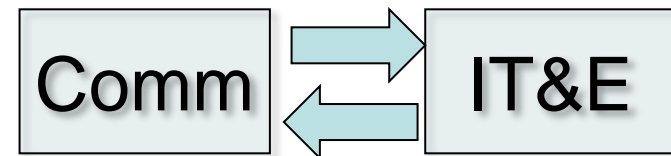
- SA Information requirements
- SA Algorithms for integrated flight testing

- Analysis and results from prototype CNPC system development/testing/simulations



- Airworthiness requirements
- Appropriate regulations

- Prototype CNPC system for integrated flight tests
- Surrogate and manned aircraft for integrated flight tests



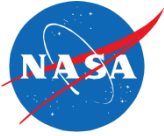
- Results from integrated tests



# RTCA SC-203 Participation



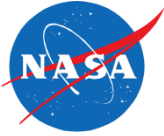
- Coordinated all NASA UAS Comm plans during formulation stage of NASA UAS in the NAS project, with WG-2 Chair
- Support weekly WG-2 telecons
- Have currently identified two working-papers for NASA development to get official discussion and feedback
  - Prototype control communication architecture and conops
  - Update on previous data requirements working paper, including validation data from UAS flights
- Latest Plenary Briefings (May 22 – 25, 2012)
  - NASA Briefing on Required Analyses, Spectrum Sharing, and Compatibility Studies for BLOS Satellite Spectrum
  - Rockwell Collins CNPC Waveform Trade Study Results
  - NASA CNPC Datalink Technology Assessment Results
  - NASA Propagation Flight Test Preparations



# ASTM F38 Participation



- NASA GRC is active in F38.01 – Airworthiness
  - 11 active standards, 12 proposed new standards
- Support weekly telecons
- Contributed one complete chapter (*C2 System Design Requirements*) to WK-28152 (Design of the Command and Control System for small Unmanned Aircraft System (sUAS))
- Reviewed & commented on rest of this document, as well as other draft standards: construction, training, quality control, etc.



## Other Partnerships



- Cost Sharing Cooperative Agreement for development of prototype CNPC radio



- Participation and data input to FAA research topics on time critical control communications latency and repetition rate simulations
- Collaborating with Security SMEs on co-development of material for Communication MASPS
- Collaboration with spectrum SMEs on WRC, ICAO, and Spectrum Authorization





# Questions?

*Jim Griner (Glenn)*  
[Jgriner@nasa.gov](mailto:Jgriner@nasa.gov)



National Aeronautics and Space Administration



# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

**Presented by: Ms. Kelly Hayhurst**

**Project Engineer, Certification Subproject**



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 27, 2012



# Certification Subproject Outline



- Technical Challenge, Context, and Scope
- Goal and Primary Objectives
- Background, Approach, and Accomplishments for each Objective
  - Objective 1: UAS Classification
  - Objective 2: Hazard and Risk-related Data
  - Objective 3: Airworthiness Case Study
- Milestones & Important Dates
- Link to Other Subprojects
- Summary



# Certification



FY	Technical Activity
FY12	Develop requirements and seek sources for a virtual type certificate
FY13	Hazard/risk-related data collection recommendations; Airworthiness classification/avionics standards approach selection
FY14	Initial hazard and risk-related data collection report
FY15	Airworthiness classification/avionics standards approach validation; Airworthiness classification/avionics standards final recommendations; Final hazard/risk-related data collection report
FY16	Final type design certification criteria report

## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and [certification requirements and procedures](#) for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Lots of Certifications



- **FAA is responsible for certifying many aspects of the aviation system, as part of their role as regulator**
  - Aircraft are airworthy -- suitable for safe flight
  - Aircraft can comply with operational requirements
    - Interoperability with other aircraft
    - Interaction with air traffic management
  - People involved
    - In aircraft operation
    - In air traffic management
  - Production, maintenance, and continued airworthiness of aircraft
- **Formulation of regulation, policy, and standards for each type of certification requires substantial technical data and analysis**
  - Certification subproject is contributing specifically to airworthiness certification



# Airworthiness Certification Focus

## Title 14 Code of Federal Regulations (CFR)

*a.k.a. Federal Aviation Regulations (FARs)*



No person may operate an aircraft unless it is in **an airworthy condition (14 CFR 91.7a)**

– **Conforms to its type design and is in a condition for safe operation (14 CFR 3.5)**

- **Focus is not limited to any specific type or size of UAS**
- **Particularly interested in systems/avionics (14 CFR xx.1309)**
  - Equipment that can affect takeoff, continued flight, landing, or environmental protection
  - Because many of the unique aspects of UAS are encompassed by avionics



# Why Focus on Airworthiness?

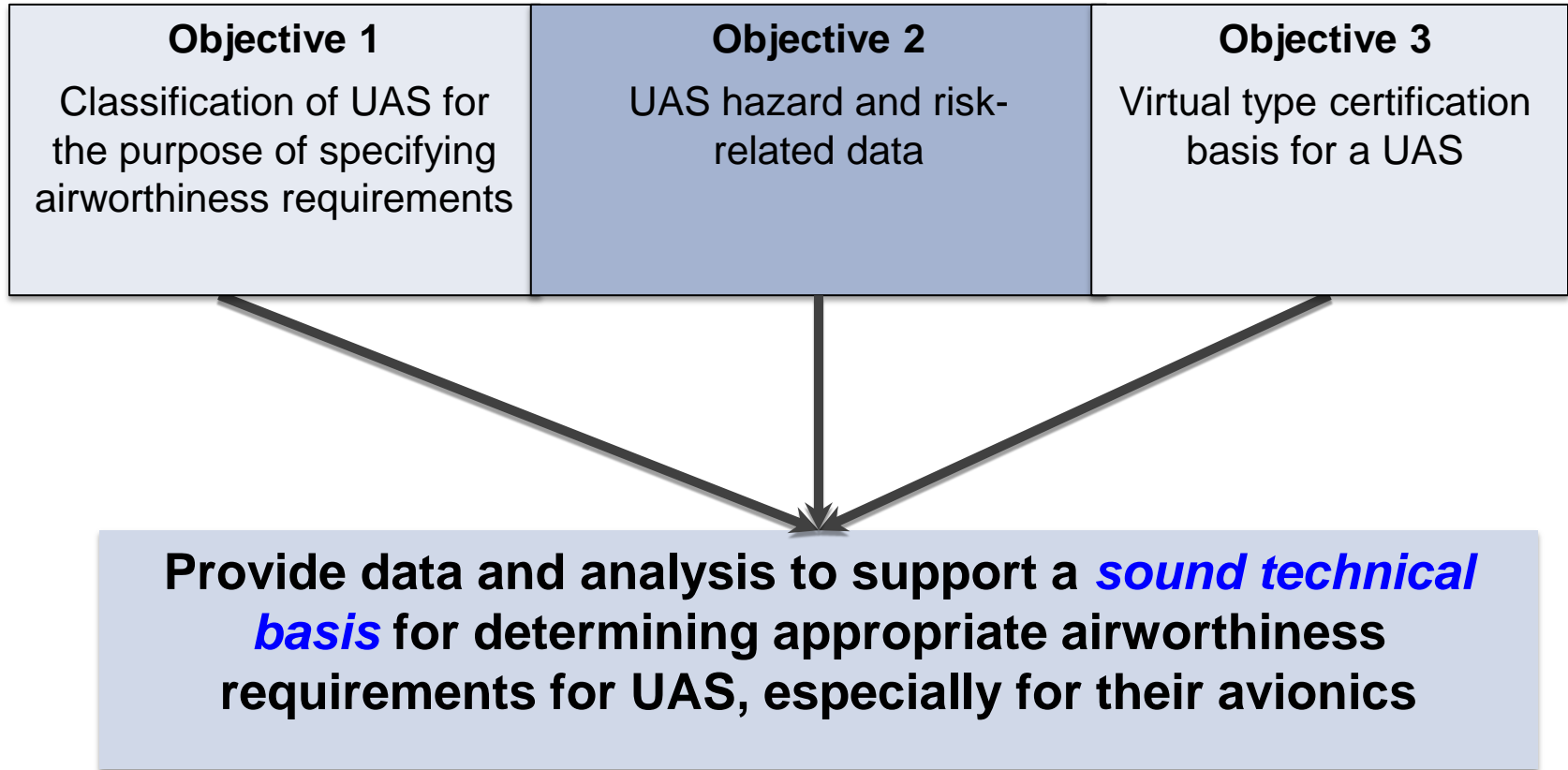
1. Lack of civil airworthiness requirements for UAS, especially their avionics systems
  2. Lack of safety-related data available to support decision making for defining airworthiness requirement
- **FAA Key Research Need: help defining a UAS certification basis that supports necessary equipment design for civil certification** [\*FAA UAS Research, Development, and Demonstration (RD&D) Perspectives for the NextGen Timeframe (2016-2025)", draft as of August 2011]
    - Corollary 1: understanding avionics/complexity as a factor in classification
    - Corollary 2: hazard and risk-related data, beyond COA (Certificate of Authorization) data
    - Corollary 3: understanding UAS failure scenarios
    - Corollary 4: simulation and modeling data on UAS systems issues
    - Corollary 5: benchmarking capabilities for testing to generate certification data
    - Corollary 6: case studies to determine a type certification basis for UAS
      - to identify UAS technology gaps for meeting regulation, and gaps in regulation addressing UAS attributes

❖ ***There are many other needs in airworthiness!***





# Certification Objectives





# Certification Subproject Team & Roles

## Certification Subproject Kelly Hayhurst, PE

### Objective 1 - Langley

#### Classification:

- Jeff Maddalon (lead)
- Jason Upchurch

#### ❖ NRAs

- Embry-Riddle Aeronautical University
- Modern Technology Solutions, Inc.

#### Validation:

- Harry Verstynen (lead)
- Robert Thomas
- Cathy Buttrill
- Tom Wolters
- Phil Smith
- Susan Carzoo
- Leigh Garbs
- Mike Cronauer

#### ❖ NRA

- Saab Sensis

### Objective 2 – Ames

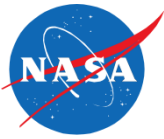
- Francis Enomoto (lead)
- Johann Schumann
- David Bushnell
- Guillaume Brat
- Ewen Denney
- Ganesh Pai

#### ❖ NRA

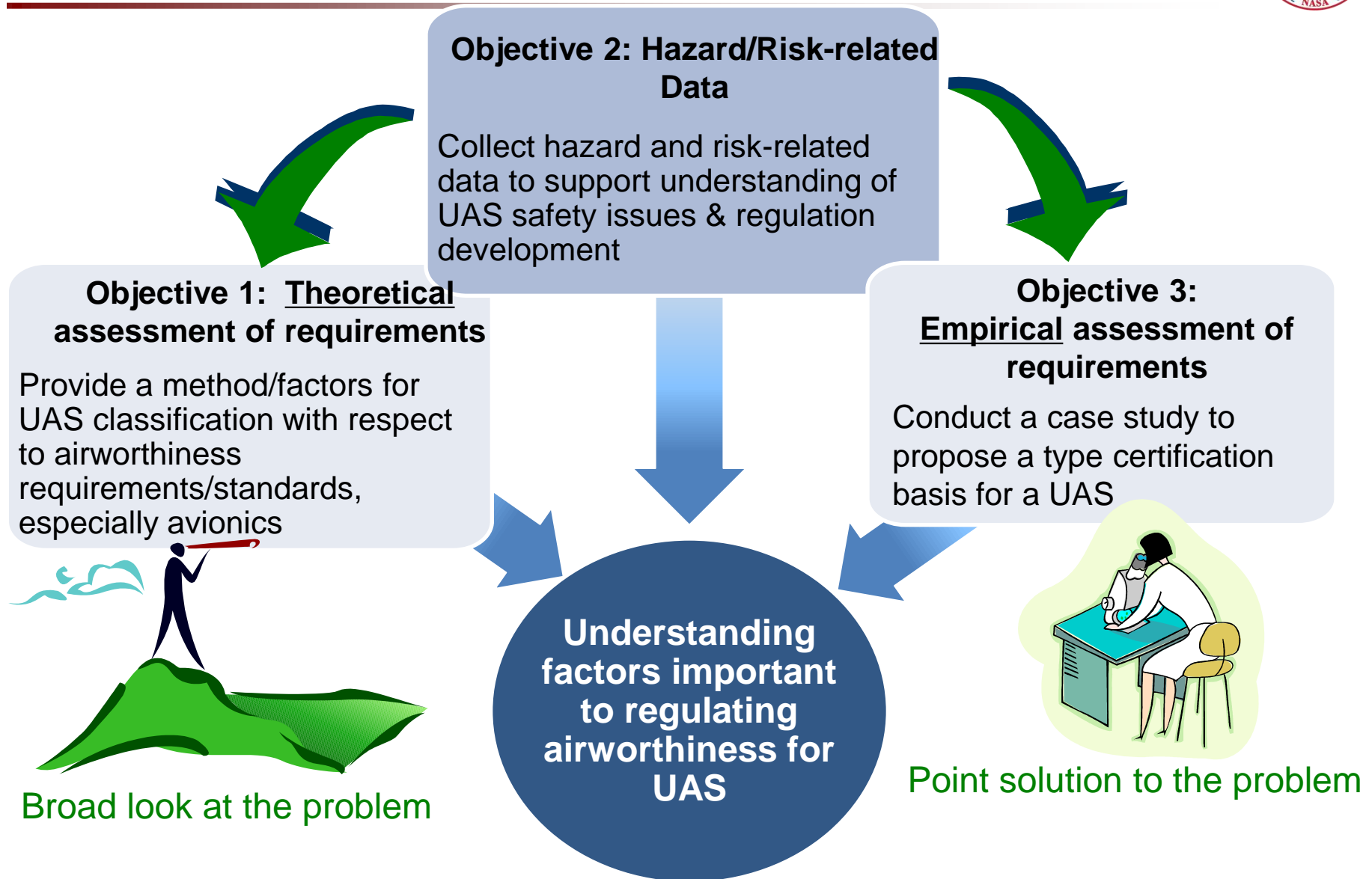
- University of Michigan

### Objective 3 (in planning)

- Kelly Hayhurst (lead)
- Frank McCormick (FAA Designated Engineering Representative)
- Harry Verstynen
- Others (to be determined)
  - subject matter experts in airworthiness certification



# Relationship Among Objectives

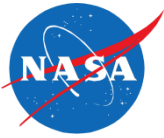




# Objective 1 (Classification) Approach



- **Classification helps ensure that systems are regulated in light of safety implications**
  - Systems that pose a similar risk are held to the same standard
    - Systems that pose greater risk are held to a higher standard
    - Systems that pose a lower risk are not unduly burdened by regulation
  - ❖ *What factors should be considered in classifying UAS for specification of airworthiness requirements?*
- **Approach**
  - Identify and assess existing approaches for UAS classification
    - Factors used in classification, assumptions, rationale, and implications
  - Identify similarities/differences/benefits/limitations
    - Synthesize key concepts
  - Analyze and draw conclusions for further assessment
    - Share findings with the FAA, with the intent of determining need for further study/validation
  - Investigate methods needed for concept validation
    - Consider how modeling and simulation could help validate airworthiness concepts



# Objective 1: Accomplishments



- ✓ Reviewed FAA policy and regulation related to aircraft classification
- ✓ Investigated and drafted a white paper describing existing and proposed UAS certification approaches
  - From a civil context:
    - In the US, including FAA, RTCA, ASTM, MIT, MITRE
    - International, including Australia, United Kingdom, Japan, Israel, EASA, and Joint Authorities for Rulemaking on Unmanned Systems (JARUS)
  - From a military context:
    - DoD, United Kingdom, France, NATO, ....
  - Begun to incorporate classification results from two NRA's: Embry-Riddle and MTSI
- Started assessing similarities and differences
- Investigating other approaches to ensure completeness of classification activities
- Developing initial concepts to support validation



# Objective 1 (Classification) Accomplishments



- **Lots of activity in civil UAS regulatory issues!**
  - New regulation appearing frequently: Malaysia, Czech Republic
  - Multiple aviation rulemaking committees
  - Numerous pertinent documents
    - ICAO Circular 328 (2011) – Unmanned Aircraft Systems
    - RTCA DO-320 (2010) and EUROCAE ER-004 (2011)
    - EASA Policy Statement E.Y013-01 (2009) – Airworthiness Certification of UAS
    - Australian CASA CASR Part 101 (2002)
    - NATO STANAG 4671 – Unmanned Aerial Vehicles Systems Airworthiness Requirements
- **Common theme:** emphasis on leveraging existing airworthiness regulation and guidance
  - Use an attribute (e.g., kinetic energy) as a means to determine which existing airworthiness requirements apply; e.g., 14 CFR Part 23, 25
  - Develop “special conditions” to cover those aspects not covered in regulation
    - e.g., emergency recovery capability, command and control link, control station



# Embry-Riddle Aeronautical University (ERAU) NRA Supporting Classification



- Principle Investigator: Dr. Richard Stansbury
  - 1-year award, started September 2011
- Approach:
  - Assess parameters that may be relevant to classification
  - Rank parameters based on how strongly they lead to desired behavior of UAS operations
  - Show how a classification system can be developed from the ranked parameters
- Findings to date:
  - Highest ranking parameters were operational in nature
    - Population density below aircraft, airspace classification, proximity to runways
  - Other high ranking system parameters were related to reliability and handling contingencies



# Modern Technology Solutions Inc. (MTSI)

## NRA Supporting Classification



- Principle Investigator: Jonathan Oliver
  - 1-year award, started September 2011
- Approach:
  - Evaluate existing classification schemes and identify factors/criteria affecting classification
  - Interview subject matter experts
  - Assess results to establish trends and formulate recommendations based on common themes
- Findings to date:
  - UAS classification should be as similar to the manned aircraft classification scheme as possible
    - Will enable the smoothest implementation for regulators, users, and controllers
  - Weight/size, airframe type, propulsion type, and complexity as the most useful classification factors
    - Because these factors are well understood by regulators





# Objective 1 (Validation) Approach

- Airworthiness requires understanding reliability and failure modes and effects at the UAS system and component level. Capabilities to that end do not exist in much of the UAS industry, especially for UAS that use uncertified avionics systems.
  - ❖ *How can we best use modeling and simulation to provide relevant and timely airworthiness data?*
  - ❖ *How can we best leverage existing capabilities to meet the special needs for UAS; e.g., simulation models, equipment, expertise, ...?*
- Approach: Investigate how modeling and simulation capabilities can add value to the evaluation of airworthiness issues
  - Examine how simulation data could be used to support UAS airworthiness issues, including data to support the evaluation of candidate classification systems
  - Draft a plan to investigate...
    - How can the failure of one component or subsystem affect the airworthiness of the UAS as a whole?
    - How does the failure of a UAS affect NAS operations?
    - What mitigations can be applied and where? (design, operational, procedural)



# Objective 1 (Validation) Accomplishments



- Developed a conceptual approach for a UAS systems validation lab that would be suitable for early collection of UAS airworthiness data
  - Make maximum use of existing hardware and software
- Initiated prototypes of capabilities necessary to represent a typical mid-sized UAS
  - Adapting lunar landing visual simulator to UAS visual line-of-sight simulator
    - Utilizes the same database as an existing COA for UAS testing
  - Adapting existing aircraft performance models to UAS models
  - Adapting existing flight management software to UAS application
  - Developed generic ground station interface from open source software
- Initiated development of a research plan to identify studies that could take early advantage of the initial operating capability
  - Certification subproject is the primary driver
  - FAA coordination underway
  - Integrate results from NRA studies and airworthiness case study as available



## Objective 2 (Hazard Data) Approach



- Little component failure, incident, or accident data exists from UAS operation in a civil context
  - ❖ *What can we learn from data gathered from existing non-commercial use?*
  - ❖ *Who is collecting what data and how?*
  - ❖ *What is really needed to support regulation, policy & standards?*
- Approach:
  - Determine data needed to support development of regulation/policy
    - Consider operational and technical risks associated with UAS
      - e.g., loss of control, loss of separation, performance degradation, component failures, etc.
  - Identify existing data sources and evaluate gaps
  - Investigate data analysis methods needed to identify UAS safety issues
    - Include those for sparse data sets
  - Evaluate options for data collection/storage
    - Determine suitability of existing databases or other options for UAS safety data
  - Document recommendations for hazard and risk-related data collection



# Lots of Relevant Data (What could be collected)



## Electronic Data

Telemetry  
Ground Control Station  
NAS-Oriented  
On-board Recorder

Detailed information covering dynamics, electronics, software, etc.  
Mission and control information  
Air traffic center information; e.g., radar and weather  
Autopilot and payload information

## Operations and Incidents/Accidents

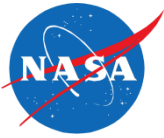
Maintenance Logs  
Incident/Accident Reports  
Mission Profile and Plans

System reliability and repair information  
Situational awareness for incidents/accidents (air and ground)  
Combined with telemetry & other data, actual vs. plan comparison

## UAS Development Data

Test and Certification  
Performance  
Aerodynamic Models

Information on how the vehicle was tested and certified  
Major vehicle characteristics; e.g., weight, speed, range, etc.  
Detailed aerodynamic specifications and simulations



# Objective 2 (Hazard Data) Accomplishments

## NASA Data Sources



- UAS data collected to date
  - Ikhana: 2007-2009 wildfire monitoring missions 1Hz flight tracks
  - Global Hawk (GH): 2010-2011 science missions 1Hz flight tracks
  - SIERRA (Sensor Integrated Environmental Remote Research Aircraft): 2008-2012 Piccolo autopilot logs, Aviation Safety Review Board (ASRB) documents
  - Swift: ASRB documents
- Incident Reporting and Information System (IRIS)
  - 9 UAS incidents listed: Vector P, Perseus B, Helios, APV-3, SIERRA, GH
- NASA Aircraft Management Information System (NAMIS)
  - Flight reports, flight scheduling, crew currency, maintenance, and logistics
  - 4 UAS including: Ikhana, 2 Global Hawks, SIERRA
- Data to be collected
  - Langley's Small Unmanned Aerial Vehicle Lab (SUAVeLab)
  - Wallop's UAS activities
  - Dryden Remotely Operated Integrated Drone (DROID) project



## Objective 2 (Hazard Data) Accomplishments Data from External Organizations



- **UAS incidents in publicly available aviation safety databases**
  - NASA/Aviation Safety Reporting System (ASRS): 21 reports
  - NTSB: 6 reports
  - FAA Accident/Incident Data System (AIDS): 2 reports
  - US Air Force/Accident Investigation Board (AIB) reports: 61 summary reports
  - Department of the Interior & US Forest Service, Aviation Safety Communiqué (SAFECON) database: 4 reports
- **External organizations contacted**
  - Mike Hutt, US Geological Survey, UAS project manager, Ravens and T-Hawks
  - Keith Raley, Department of the Interior, Aviation Safety manager
  - Tom Zajkowsky, US Forest Service, UAS demonstration projects
  - Ella Atkins, University of Michigan, sUAS risk analysis NRA
- **External organizations in work**
  - FAA
  - USAF Safety Center
  - Universities (New Mexico State University, University of Alaska, etc.)
  - Manufacturers

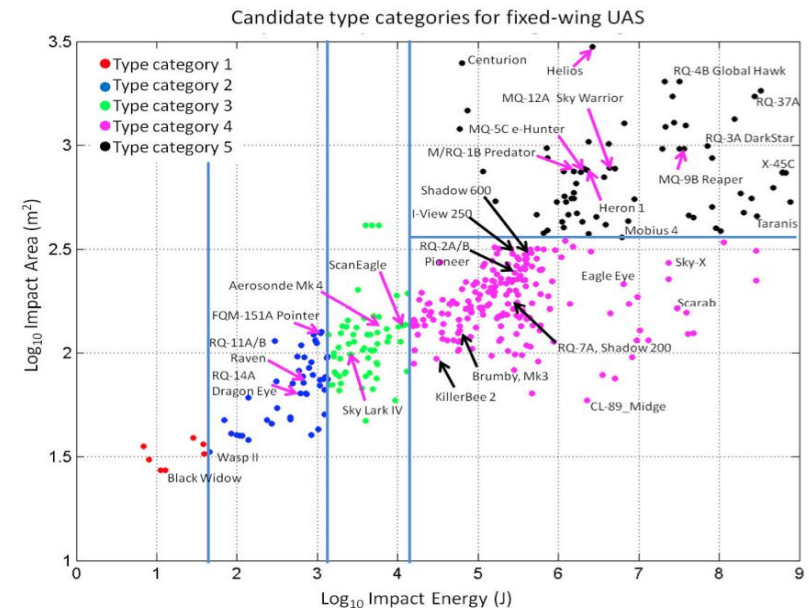


# Objective 2 (Hazard Data) Accomplishments

## Data Analysis



- **Statistical methods for classification**
  - Define classes of UAS
  - Define mission/application classes
  - Support risk analysis
- **Risk analysis**
  - System risk analysis
  - Safety cases
  - Software risk analysis
- **Text mining**
  - Incident reports, maintenance logs, operator reports
- **Correlation analysis**
  - Analyze interrelationship of data from different sources
- **Statistical methods/Reliability Analysis**
  - Calibrate physical and prognostics models
  - Identify system/component reliability issues
  - Provide information for prognostics and Vehicle Health management (health-based maintenance)



[ref. Clothier, Reece A. UAS Classification: Key to effective airworthiness and operational regulations. In Royal Aeronautical Society Unmanned Aircraft Systems Specialist Group, UAS Classification Workshop, 24 June 2011, London, UK.]



# University of Michigan NRA Support for Objective 2



- **Risk Analysis of Small Unmanned Aircraft Systems (sUAS) in the NAS**

PI: Ella Atkins, University of Michigan

Co-PI: James Luxhøj, Rutgers U., Daniel Salvano, SAIC

1 year award, starting in September 2012, with 2 1-year options

- **Approach:**

- Characterize small UAS risk in the context of specific platform characteristics and mission scenarios
  - Using their Michigan Autonomous Air Vehicle (MAAV) Quadcopter
  - Study risks associated with those single or multiple failures
- Develop small UAS Hazard Taxonomy based on regulatory perspective
- Provide a systematic study of UAS failures and associated safety



- **Findings to date:**

- Developed a top-down model of the failure modes for their quadcopter
  - Performed two case studies, loss of an inertial management unit and a height-sensor failure
- Performed a communications loss analysis of the SIERRA Piccolo flight logs
- Initiated collaboration with Department of the Interior, Aviation Management to share sUAS data and risk analysis of typical mission scenarios





## Objective 3 (Case Study) Background



- **NASA will provide a team of subject matter experts to work with an organization to *virtually* go through initial steps of the airworthiness certification process for a UAS**

Learn what regulations apply as is	Provide data to validate the FAA's database on applicability of current 14 CFR to UAS
Learn what regulations apply with interpretation	
Learn what regulations clearly don't apply (exemptions)	
Learn about "special conditions" needed to handle safety issues not covered by existing regulation	Provide data to FAA to help determine new regulation that might be needed
Learn whether the process itself may benefit from modification	Provide data to FAA to help formulate UAS certification process
Provide an example of going through the airworthiness certification process	Aid UAS industry in learning about airworthiness certification



## Objective 3 (Case Study) Approach

- **Approach: Follow the 14 CFR Part 21 guidance for Type Certificates**

- Draft a Product Specific Certification Plan, including

- Draft Type Certification Basis

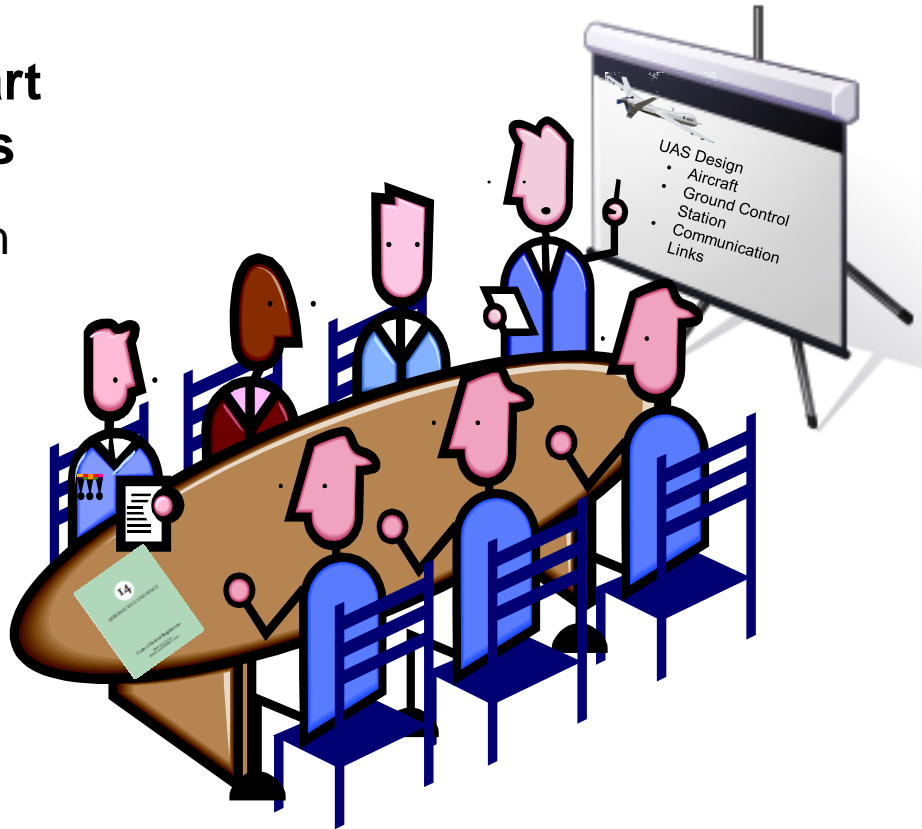
- Applicable regulations, special conditions, exemptions, optional design regulations and environmental (noise) findings

- Draft Compliance Checklist

- Specifies methods of compliance (e.g. flight test, ground test, compliance statement, analysis, inspection, etc.) for each regulation

- **Document rationale for everything!**

- **Determine applicability of results to other UAS**





## Objective 3 (Case Study) Accomplishments



- **Issued a Request for Information (February 8)**
  - Provided an overview of the purpose/activities for the case study
  - Requested info on candidate UAS, certification experience, and willingness to participate in open/public distribution of results
- **Several responses received (March 26)**
- **FAA-NASA team reviewed responses and developed options describing criteria for a good case study candidate – in preparation for a request for proposal**
  - Narrow the pool of potential case study partners
  - Options largely based on intended operational airspace, because that drives minimum required equipage
- **Briefed the Project Office (May 30)**



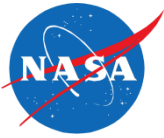
# Milestones-Dates

(does not reflect Objective 3 work)

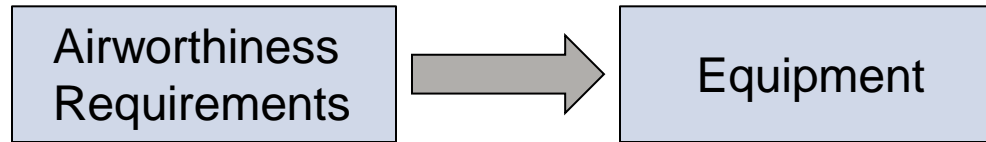


## Milestones

Results from our 4 external research awards (one award will also report in Sep '13 and 14)	September 2012
Provide recommendations for hazard and risk-related data collection to support development of regulation	December 2012
Down-select an approach for classification and determination of airworthiness standards for avionics aspects of UAS	June 2013
Initial report on data collection efforts	March 2014
Validate approach for classification and airworthiness standards	September 2014
Final report on data collection efforts	September 2015
Final recommendations for UAS classification and airworthiness standards for avionics	September 2016



# Linkage to Other Subprojects



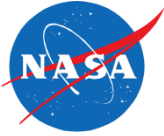
- Equipment that is part of the UAS will be subject to airworthiness requirements
  - Command and control links/radios
  - Ground control station
  - Separation or sense and avoid function
- As part of the case study, we will be examining the relevant regulations for each of those areas, as they apply (or need to apply) for that particular UAS
  - Determine the applicability of the results to the work done in the other subprojects
- We also hope to draw on the expertise in those specific areas of UAS functionality in the other subprojects



# Summary



- **Much of our first year's effort has been directed to laying the groundwork**
- **Work on planning for the case study has taken time away from the other objectives**
  - But, the case study will provide benefit back to Objectives 1 & 2
- **NRA work is starting to provide useful results to incorporate in Objective 1 & 2 activities**
- **Addition of the Objective 3 (case study) work should help with**
  - Clearly identifying the factors that affect the allocation of airworthiness requirements and the applicability of existing regulation
  - Developing a "UAS playbook" for industry to better understand civil airworthiness processes and what is needed to obtain type design certificates



# Questions?

*Kelly Hayhurst (Langley)*

*[Kelly.J.Hayhurst@nasa.gov](mailto:Kelly.J.Hayhurst@nasa.gov)*



# Back-up Charts





# Methods for Acquiring UAS Airworthiness Data



SOURCE	ADVANTAGES	DISADVANTAGES
Collect data from military UAS ops	<ul style="list-style-type: none"><li>• Large body of data</li><li>• Wide spectrum of UAS types</li></ul>	<ul style="list-style-type: none"><li>• Limited relevancy to civil/commercial ops – most vehicles considered expendable</li><li>• No ops over high density populations</li><li>• Difficult to obtain</li></ul>
Collect data from civil UAS ops	<ul style="list-style-type: none"><li>• Limited body of data</li><li>• Limited spectrum of types</li><li>• Mostly extensions of military ops</li></ul>	<ul style="list-style-type: none"><li>• Mostly uses military UAS, which were (mostly) designed to be expendable</li><li>• No ops over high density populations.</li><li>• Commercial ops N/A</li></ul>
Collect data from Commercial UAS ops	<ul style="list-style-type: none"><li>• High relevancy to UAS certification issues</li></ul>	<ul style="list-style-type: none"><li>• Commercial ops N/A until new rule published</li><li>• Likely limited to &lt;55# and VLOS in near term</li></ul>
Case Studies	<ul style="list-style-type: none"><li>• High relevancy</li><li>• Industry/FAA/NASA involvement</li></ul>	<ul style="list-style-type: none"><li>• Primarily guides <i>requirements</i> for safety data</li></ul>
Airworthiness System Integration Laboratory (SIL) Studies (Ground Capability)	<ul style="list-style-type: none"><li>• Collect statistically relevant data quickly (accelerated testing)</li><li>• Easier introduction of faults, esp. potentially catastrophic faults.</li><li>• Not process intensive (fewer safety issues)</li><li>• Repeatable environment</li><li>• Control of all variables</li></ul>	<ul style="list-style-type: none"><li>• Results need spot validation in flight</li><li>• Lower fidelity/TRL level</li></ul>



# Activities for Objective 3 (Case Study)

- **Pre-Task 1: Get a candidate UAS!**
  - review RFI and RFP responses
- **Task 1: Learn the design of the candidate UAS**
- **Task 2: Determine baseline set of airworthiness requirements, e.g., Part 23, 25, 27, or 29**
  - leverage FAA work underway to assess the applicability of existing 14 CFR to UAS
  - provide justification for that baseline
- **Task 3: Determine specific requirements**
  - which regulations apply, as is + rationale
  - which do not apply (exemptions) + rationale
  - which apply, maybe with some interpretation + rationale
- **Task 4: Identify the need for special conditions**
  - for safety issues not addressed in the FARs or other guidance + rationale
- **Task 5: Determine the method of compliance for each regulation in the certification basis**
- **Task 6: Assess applicability of results to other UAS**

Certification  
Basis

Compliance  
Checklist



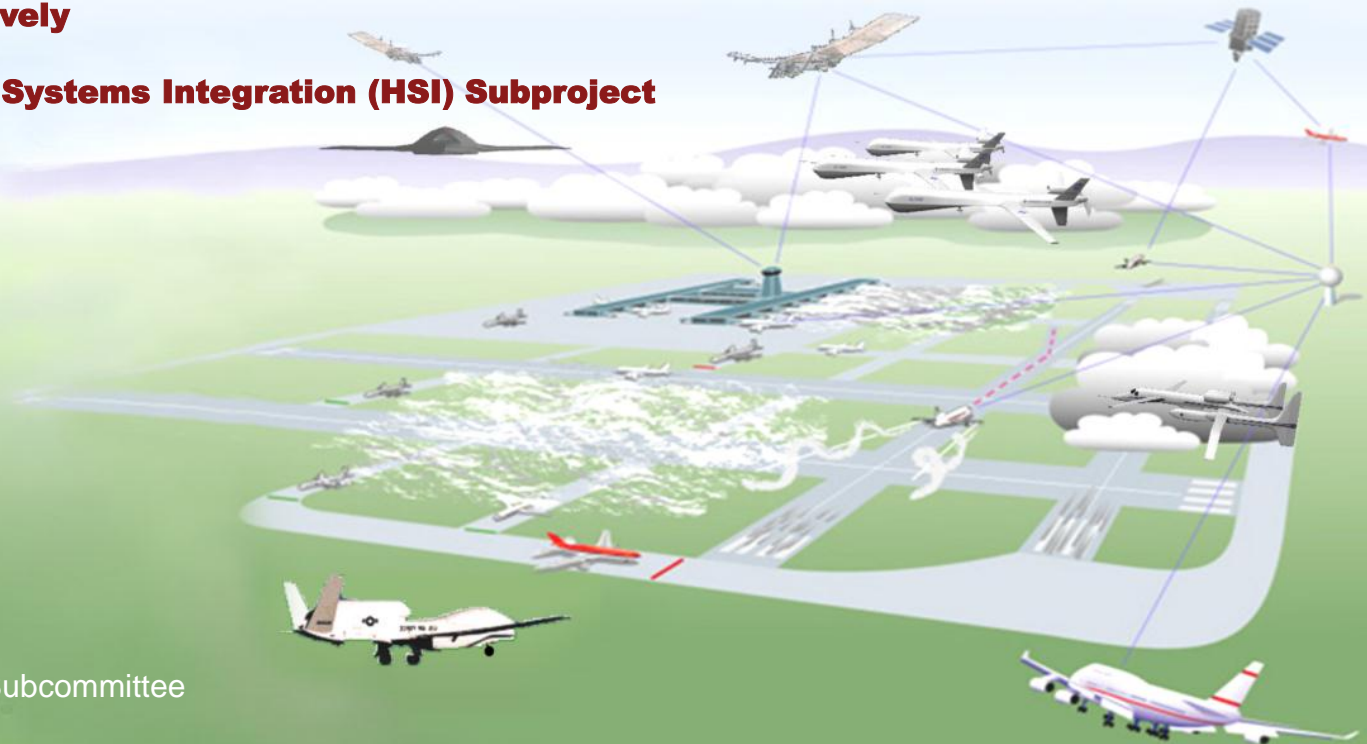
National Aeronautics and Space Administration



# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

**Presented by: Mr. Jay Shively**

**Project Engineer, Human Systems Integration (HSI) Subproject**



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 28, 2012

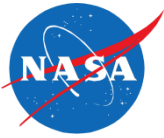


# Human Systems Outline

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- Human Systems Team
- Barriers/Objectives/Approach
- Workshop
- Information Requirements
- Facilities
- Part-task Simulations
- Recommendations for guidelines
- Linkages to other subprojects



# Human Systems Team (on-site at NASA Centers)



- Jay Shively ARC
- Anna Trujillo LaRC
- Mark Pestana DFRC
- Walter Johnson ARC
- Jamie Whilhite DFRC
- Kurt Sanner DFRC
- Ray Comstock LaRC
- Vern Battiste ARC - SJSUF
- Lisa Fern ARC – SJSUF
- Alan Hobbs ARC - SJSUF
- Dominic Wong ARC -UARC
- Ray McAdaragh LaRC
- Mike Marston DFRC
- Beth Wenzel ARC
- Randy Begault ARC
- Caitlin Kenny ARC –SJSUF
- Quang Dao ARC - SJSUF



# Human Systems Integration



FY	Technical Activity
FY12	Workshop; GCS information requirements; Candidate GCS Suite
FY13	1 <sup>st</sup> UAS class guidelines complete
FY14	Integrated Human-In-The-Loop simulation
FY15	Prototype interface/candidates II definition; Human-In-The-Loop simulation II
FY16	Flight Test Series 4; Final guideline recommendations

## Airspace Integration

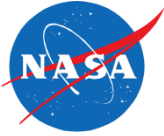
Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Human Systems Integration



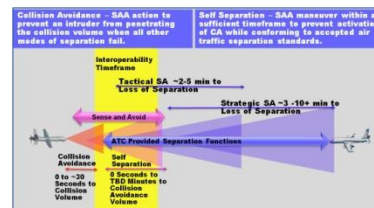
- Technical Barriers:
  - Lack of Standards
  - Lack of requirements/definition of what is needed to operate in the NAS
- Objectives:
  - Develop database for understanding requirements
  - Develop recommendations for GCS guidelines to operate in the NAS
- Technical Approach
  - I. Determine information requirements
  - II. Instantiate in proof of concept GCS
  - III. Develop recommendations for guidelines



# HSI Subproject

Efficiently manage contingency operations w/o disruption of the NAS

Seamlessly interact with SSI



Coordinate with ATC - respond w/o increase to ATC workload



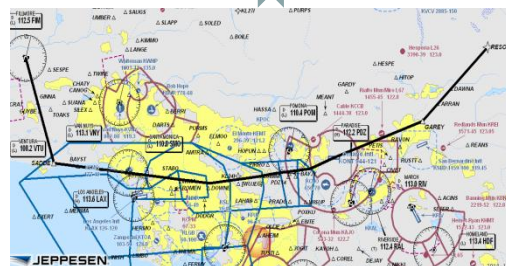
Research test-bed and database to provide data and proof of concept for GCS operations in the NAS



Human factors guidelines for GCS operation in the NAS



Ensure operator knowledge of complex airspace and rules



Standard aeronautical database for compatibility



Traffic information for situation awareness and separation (NextGen)





# Scope



## In scope:

- NASA will address those issues related to UAS integration into the NAS – based on information requirements analysis
- Develop guidelines for a UAS/GCS to operate in the NAS/ Demonstrate proof of concept
- Generic issues (e.g., operator FOV) when needed to effectively test UAS-NAS integration
- Best Human Factors practices used in GCS addresses human-automation interaction, integrated caution, warning, and advisory, etc.

## Out of scope:

- Determination of pilot v. non-pilot qualifications for UAS operation



# Scope



**Primary\***



**Support**



Class of UAS User Interaction	Airspace Req'd	Cap/ Req
Small (Raven) R/C, Portable	G (2k), TFR	Ground based ?
Mid-Size (Shadow) Semi-Auto, Mobile	E (10k)	Sense & Avoid, Traffic
Large (Predator) Manual, Fixed	A (18-45k)	Sense & Avoid, Traffic
Large (Global Hawk) Auto, Fixed	A, E (18-60k)	Sense & Avoid, Traffic

**\* Employed by DHS, USAF, Army**



# NASA UAS in the NAS Workshop (23-24 May 2011)



- Objectives
  - Technical Presentations
  - Identification of Research Challenges (2 lists formed)
  - External assessment of UAS in the NAS HSI plan
- 45 Human Factors experts from:
  - Industry
  - Academia
  - Government
- Location: JPDO, Washington DC





# NASA Workshop



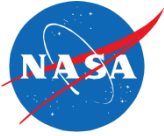
- 45 Attendees
- Industry and academia
- 16 talks
- FAA (7), AFRL,
- MIT, CSULB, ASU, ERU, WSU,
- Boeing, SAIC, MITRE, SA Tech, Research Associates, HF Design



# Workshop Accomplishments



- Brought community together to:
  - Identify Issues
  - Identify Programs
  - Review previous/current efforts
- Identified potential (and needed) collaborations
- Published proceedings
- Tentative plans for follow-up at end of Phase I



# I. Determine information requirements

---



- Phase of Flight
- Functional
- Regulatory
- Catalog of GCS



# Phase-of-Flight Requirements



- A collection of requirements and their associated tasks during each phase-of-flight
  - Leveraging various sources of information
    - FAA, SC-203, Pilot Interviews, etc.
  - Break down of requirements and related tasks
    - Currently migrating the requirements and tasks from each phase-of-flight into the master requirements chart (shown below)
      - Phase of Flight includes: Preflight Planning, Start & Taxi Operations, Launch-Takeoff & Departure, En Route, Aerial Work, Descent & Landing/Recovery, Taxi In (Post Landing)
    - Redesigned the master requirements chart
      - To better show relationships between each requirement and it's associated task as well as improve chart usability

Information Requirements Preflight Planning Start & Taxi Operations Launch-Takeoff & Departure En Route Aerial Work Descent & Landing/Recovery Taxi In (Post Landing) References +									
		SURFACE ENVIRONMENT		AEROSPACE ENVIRONMENT			SURFACE ENVIRONMENT		CONTINGENCY
		Preflight Planning		Start and Taxi Operations	Launch/Takeoff and Departure	En Route	Aerial Work	Descent and Landing/Recovery	Taxi In
AVIATE/CONTROL FUNCTIONS		The aviate/control function is how the UAS pilot sends commands to the UA (telecommand) and then receives confirmation that those commands are executed and that the aircraft is operating in the correct manner (telemetry). This function relies on the telecommands sent from the GCS to the UA and the telemetry sent back from the UA to the GCS; or on preprogrammed navigation for autonomous control; or by physical movement of the aircraft (e.g., tow). <sup>1</sup>							
Airspeed	Requirement	Monitor Airspeed <sup>2,3</sup>							
	Associated Task								
	Requirement								
Altitude: AGL (above ground level)	Requirement	Position: 1 altitude (2) altitude (relative and absolute, verified accuracy) (3) range and range rate <sup>3</sup>							
	Associated Task								
	Requirement	Distance from ground data terminal <sup>2</sup>							
Altitude: MSL (meters above sea level)	Requirement	Position: 1 altitude (2) altitude (relative and absolute, verified accuracy) (3) range and range rate <sup>3</sup>							
	Associated Task								
	Requirement								
Engine: RPM (revs/min)	Requirement	Engine performance parameters <sup>2</sup>							
	Associated Task								
	Requirement								
Vertical Velocity	Requirement	Vertical Trend							
	Associated Task								
	Requirement	Vertical Rate <sup>2</sup>							
	Requirement	Vertical speed <sup>2</sup>							
	Associated Task								
TASKS		Control the movement of the aircraft on the surface and monitor status <sup>1</sup>		Control movement of the aircraft and monitor status <sup>1</sup>					
		Performing takeoff/launch and establish cruise flight <sup>2</sup>		Transitioning from cruise flight to pre-flight, landing or other intended flight plan <sup>2</sup>					
		Identify resolution, estimate resolution state and threat level, expediting to avoid a collision as needed <sup>2</sup> (see AWC-001)							
Primary Functions <sup>1</sup>		Control the aircraft		Control the aircraft					
		Monitor aircraft health and status, and confirm telecommand execution		Monitor aircraft health and status, and confirm telecommand execution					



# Functional Information Requirements



- Literature search
  - AIM, Air Traffic Operations manual, FARs, etc.
  - LaRC information requirements categorized by aviate, navigate, communicate, manage systems/payload
  - Success criteria based on requirements for GA pilots
    - sUAS  $\cong$  GA aircraft
- Living document → will be expanded and modified based on:
  - Survey and phone interview responses
  - Human-in-the-loop simulations
  - Flight tests

Tracking Number	GCS Information Requirement	Task / Function ( A, N, C, P )	Success Criteria (PTS, FTE)	Airspace Class	Reference(s)
1	Airspeed	A	(+/-) 10 KIAS [PTS]	G	6
3	Altitude	A	(+/-) 100 ft. [PTS]	G	6
7	Intended Route of Flight w/ standard NAS WPTS, fixes, airports, etc.	N	Approved Flight Plan; Well-established contingencies for lost link, lost comm	G	
36	Notify Police Air Cmd and/or Dispatch of launched UAS	C	Full and complete coordination w/ATC	G	OSD
38	Wx conditions prior to launch, during mission, as well as during Ldg & recovery.	P	Safe Ops within A/C performance envelope	G	ATIS





# Functional Information Requirements



- Survey & phone interviews
  - Elicit GCS information requirements via survey and phone interviews from:
    - (1) UAS and sUAS pilots
    - (2) Manned-aircraft pilots
    - (3) Air traffic controllers



Similar questions asked so that answers could be compared

- I believe that small UAS (under 55 lbs) without ATC communications and without transmitting position (ADS-B) information will need separate or special airspace for their operations.

**Strongly Disagree**

**Strongly Agree**

- As of June 1:
  - (1) 18 manned-aircraft responses → scheduling phone interviews
  - (2) 3 ATC responses
  - (3) 2 UAS responses



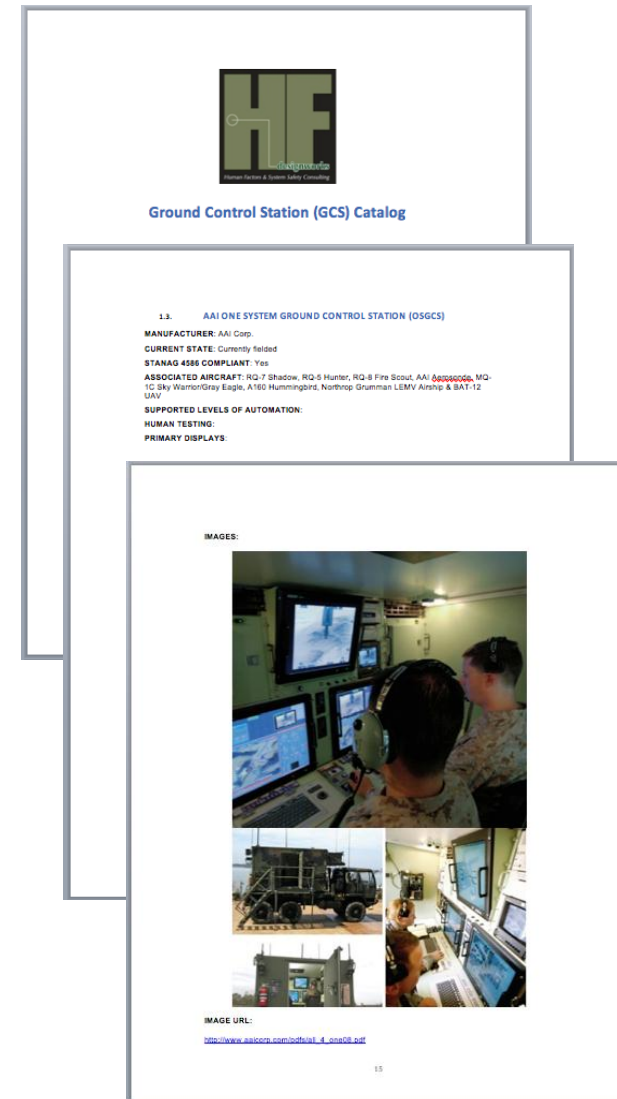
# Regulations Requirement Analysis



- Collaborating with FAA
  - Using their input on fields for review and analysis
  - Coordinating with an ongoing review of Parts 27 and 29
- Regulations and other material to be reviewed
  - Design regulations Parts 23 and 25
  - Related ACs and other documents identified as relevant in Parts 23 or 25
- Possible other regulations and material for additional review
  - Operations regulations Parts 61, 91, 121, 125, 135
  - Aeronautical Information Manual
- Results will include description of the potential impact of regulations for
  - GCS design
  - GCS implementation
  - GCS maintenance
  - UAS operations

# UAS in the NAS: GCS Catalog

- A catalog of findings from a comprehensive review of publically available Unmanned Aircraft System (UAS) Ground Control Stations (GCS)
  - Based on publicly available information
  - For UAS with aircraft greater than 55 lbs.
  - Includes ground control stations developed worldwide
  - Each entry includes description of system, images, vendor contact information, manufacturer, and six critical elements used for further categorizing the systems:
    1. Current State (state of art vs. state of practice)
    2. STANAG 4586 compliance
    3. Associated aircraft
    4. Supported levels of automation (LOA)
    5. Human testing during development (Y/N)
    6. Primary displays used for GCS





# UAS in the NAS: GCS Catalog



- An online version of the catalog has also been developed
  - Includes all information found in document-based catalog
  - Also includes browsing, search, filter, and hyperlink capabilities

## HF DESIGNWORKS | GROUND CONTROL STATION CATALOG

Home GCS Catalog



(U.S. Air Force photo/Senior Airman Nadine Y. Barclay)

### Introduction

This report presents the findings from a comprehensive review of publically available current Unmanned Aircraft System (UAS) Ground Control Stations (GCS) information. Included in this report is a list of current systems, aircraft control capabilities, level of automation (and accompanying control paradigm category), STANAG 4586 compliance, primary displays, and human testing/research.

Note that due to the proprietary nature of some of the information related to GCS, all information provided in this report is available from the public domain. Information was gathered from web searches, commercially available flight simulation software (where applicable), published research reports, vendor marketing information, and information obtained through discussions with UGCS vendors.

### Composition of a GCS

The term GCS as is described in this catalog represents controllers that human operators interact with to control an unmanned aircraft. GCS come in a variety of sizes and styles. Some GCS have been

## HF DESIGNWORKS | GROUND CONTROL STATION CATALOG

Home GCS Catalog

### A-LEVEL AEROSYSTEMS ZALA AERO OPTIONAL GROUND CONTROL STATION (GCS)

MANUFACTURER: A-Level Aerosystems

CURRENT STATE:

STANAG 4586 COMPLIANT:

ASSOCIATED AIRCRAFT: A-Level Aerosystems ZALA 421 Family of UAS

SUPPORTED LEVELS OF AUTOMATION:

HUMAN TESTING:

PRIMARY DISPLAYS:

[Read more >](#)

### A-LEVEL AEROSYSTEMS ZALA AERO STANDARD GROUND CONTROL STATION (GCS)

MANUFACTURER: A-Level Aerosystems

CURRENT STATE:

STANAG 4586 COMPLIANT:

ASSOCIATED AIRCRAFT: A-Level Aerosystems ZALA 421 Family of UAS

SUPPORTED LEVELS OF AUTOMATION:

HUMAN TESTING:

PRIMARY DISPLAYS:

[Read more >](#)

### AAI EXPEDITIONARY GROUND CONTROL STATION (EGCS)

MANUFACTURER: AAI Corp.

CURRENT STATE: Currently fielded

STANAG 4586 COMPLIANT: Yes

ASSOCIATED AIRCRAFT: AAI Aerosonde Mark 4.7

SUPPORTED LEVELS OF AUTOMATION:

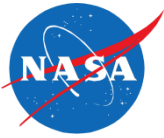
HUMAN TESTING:

PRIMARY DISPLAYS:

[Read more >](#)

OR

☐ US vendor  
☐ Uses automation  
☐ Stanag Compliant



## II. Instantiate in Proof of Concept GCS

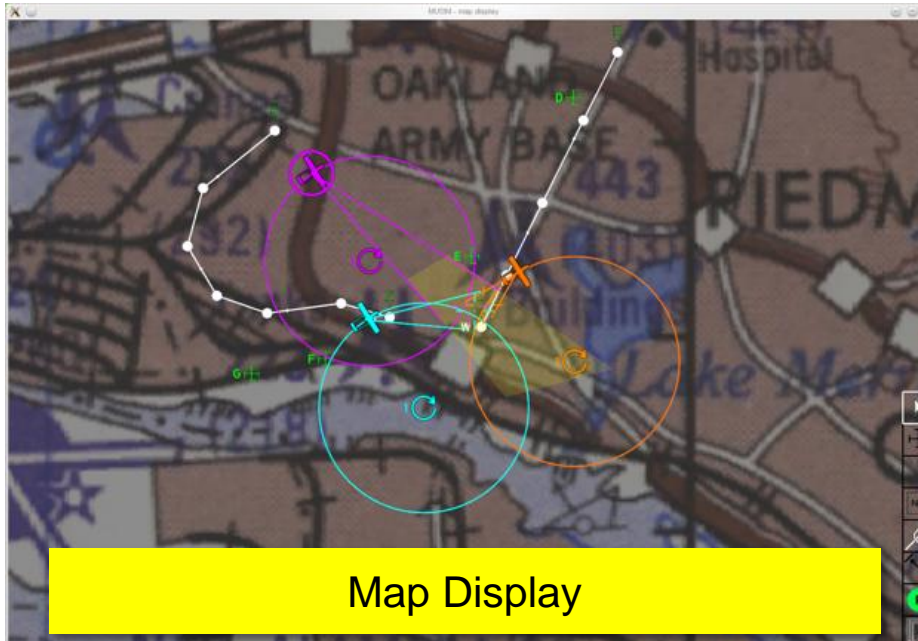


- Facilities
  - Multiple UAS Simulator (MUSIM)
  - Vigilant Spirit Control Station (VSCS)
  - Multi-Aircraft Control System (MACS)
  - Cockpit Situation Display (CSD)
  - LaRC
- Examples of simulations to develop GCS
  - Part Task 1 – ARC - Baseline UAS/NAS
  - Part Task 2 – ARC - Delegated Separation
  - Part Task 3 – LaRC – sUAS, LOS
  - Part Task 4 – Measured Response (MR), CSULB
  - Part Task 5 – ARC, VSCS, Contingency Management





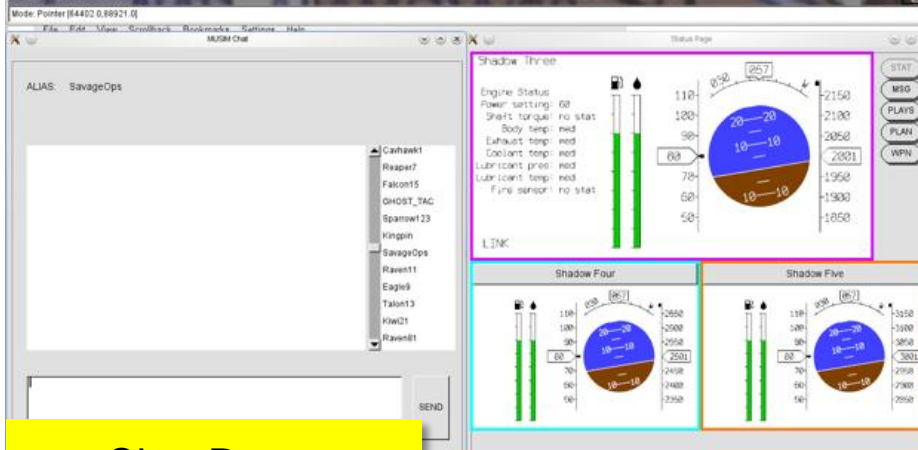
# Multiple UAS Simulator (MUSIM)



Map Display



Sensor/Camera Windows



Chat Room



Multi-Function Display

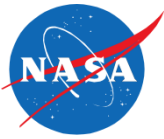


# Multiple UAS Simulator (MUSIM)



- MUSIM) is a simulation testbed, consisting of a Linux-based PC with a keyboard, mouse, and SpaceExplorer Connexion input device
  - Shadow 200 and MQ-1 Predator models have been used
- Mission tasks have included:
  - Supervisory control of multiple UASs
  - Airspace/Clearance status
  - Monitoring aircraft systems status
  - Intelligence, Surveillance and Reconnaissance tasks
  - Conflict avoidance
  - Radio contact with ATC
- MUSIM contains multiple displays that can be used in experiments:
  - Map display (north up)
  - Camera sensor display
  - Multi-function display
  - Alert Box
  - Timer
  - mIRC (chat client)
  - Audio alerts
- Developed by the US Army Aeroflightdynamics Directorate, RDECOM, US Army





# Vigilant Spirit Control Station (VSCS)



*Single Operator, Multiple Vehicles, Diverse Missions & Payloads, Advanced Intuitive User Interface, One Common Solution →*

**VIGILANT**  
*Spirit*  
Control Station

Innovative Operator Interface  
(Video / DVR / Mosaicing)



Dynamic Mission Planning



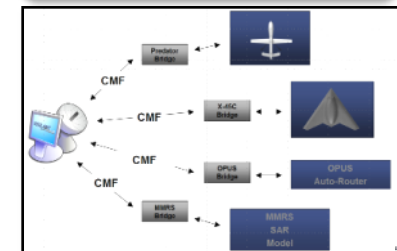
Flexible Software Architecture



Simulation



STANAG-4586  
Standard Data Link Interface








# Vigilant Spirit Control Station (VSCS)

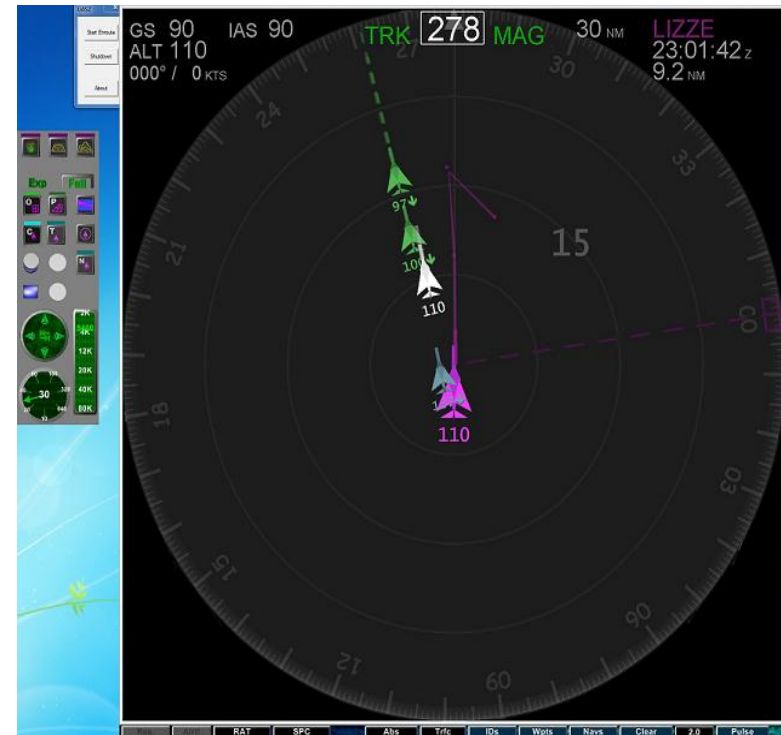


- VSCS is a simulation testbed, consisting of a Windows-based PC with a keyboard and mouse
  - Several flight model capabilities
- Mission tasks have included:
  - Combat UAS
  - Small UAS
  - Air launched UAS
  - UAS Air refueling
  - Anti-IED
  - Predator missions
  - Cooperative Ops
  - Long range strike
  - Perimeter defense
- Impact
  - 30+ customers - AF, DoD, & industry
  - 2007 & 09 Talisman Sabre, Aerial Refuel, Urban ops, Sentinel Hawk
  - Leadership: interoperability for multi-UAS control
  - Transitioned lab-validated interface concepts to the next level
  - More than 200 flight test hours
  - AFMC 2008 S&T Mgmt Award
  - 2008 USAF Outstanding Sci. Team
- Developed by the Air Force Research Laboratory





- Traffic Display developed for manned aircraft
  - Determine information, tools and features that UAS require
- 
- Aircraft color coded:
    - Green: aircraft 500 ft or more below ownship
    - White: aircraft within 500 ft above or below ownship
    - Blue: aircraft 500 ft or more above ownship
- 
- 
- The image shows a screenshot of a Traffic Display (Traffic Display) interface. On the left, there is a vertical toolbar with various icons for aircraft status and control. The main display area shows a circular radar-like view with concentric circles representing altitude ranges (30, 120, 240, 480, 960 feet). Several aircraft are plotted as icons with associated data labels. A green aircraft is labeled 'TRK 278' and 'MAG'. A white aircraft is labeled '110'. A blue aircraft is labeled '110'. The top right corner displays flight information: 'GS 90', 'IAS 90', 'ALT 110', '000° / 0 KTS', '30 NM', 'LIZZE', '23:01:4', and '9.2 NM'. The bottom left corner shows a small window with 'Start Events', 'Shutdown', and 'About' buttons.





# Multi-Aircraft Control System (MACS) controller station



- Air Traffic Controllers
- Pseudo-pilots
- Traffic generation

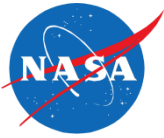




# GCS Display and Control

- PC based → portable
- Single to multiple display screens
- Different instrumentation and layout of that instrumentation possible
  - Open source software
- Manual to autonomous flight control
  - Currently have manual flight control with an RC controller
  - Have capability to incorporate:
    - (1) Traditional sidestick, rudder pedals, and throttle quadrant
    - (2) Mouse and keyboard
    - (3) Touchscreens
  - Enabling flight path display and control
- Incorporating line-of-sight via “tower view”
  - Have beyond-visual-range operations capability





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  - Have beyond-visual-range operations capability







# Part Task Simulation 1

- Objectives:
  1. To examine baseline conditions for UAS operations in the now-Gen NAS under ATC spacing rules, and
  2. To compare the effects of different display conditions in the now-Gen NAS under ATC spacing rules
- Independent Variables:
  1. Traffic display
    - no display (baseline - no currently fielded GCS have traffic displays)
    - basic 2D display with trajectories
  2. Traffic density
    - low (9-12 aircraft/sector)
    - high (12-16 aircraft/sector)
- Mission:
  - Police highway patrol support in Southern California Center airspace
  - Pre-assigned route filed with ATC with route changes partway through mission (from commander or supervisor) which requires a new flight path request from ATC
  - Operate according to current IFR procedures



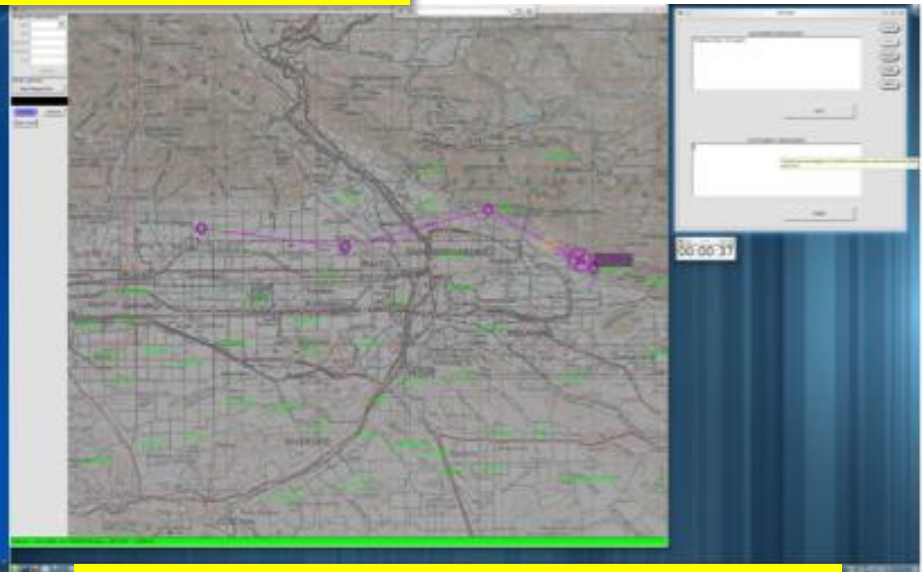
# Part Task Simulation 1

- Simulation Environment:
  - Ground Control Station: MUSIM and CSD with single GA pilot
    - CSD present in half of the trials
  - Pseudo Pilot Station: MACS (Multi Aircraft Control Station) with 1 pseudo-pilot
  - ATC Terminal: MACS with 1 retired controller

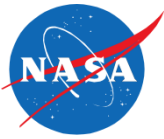
## Ground Control Station Set Up



Cockpit Situation Display (CSD)



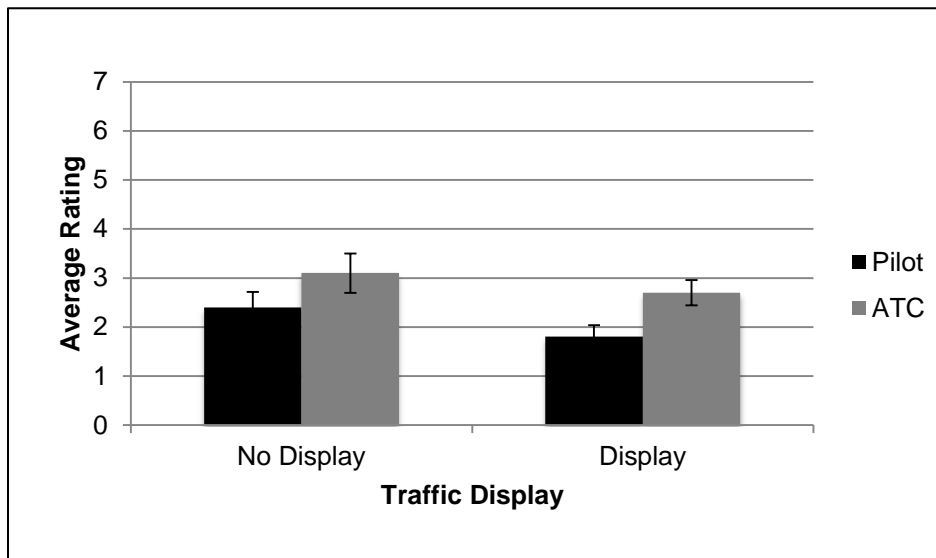
Multiple UAS Simulator (MUSIM)



# Part Task Simulation 1



- Results indicate favorable effects of having traffic information in the GCS
  - Lower ratings on the frustration dimension of workload for Pilots with CSD present
  - Lower workload ratings associated with comms/interactions for both Pilots and ATC with CSD present
  - Higher self-ratings of SA with CSD present



Pilot and controller interaction workload ratings.

Situation Awareness Statement	No Display Mean Rating	CSD Mean Rating	p
I was aware of the locations of surrounding traffic	0.9	5.4	<.001
I was confident in my assessment of the traffic situation	1.3	5.9	<.001
I was aware of traffic conflicts developing	0.8	4.3	<.001
My SA was sufficient and effective	3.1	5.0	<.01
I had the airspace information that I needed to complete mission reroutes	2.8	4.5	<.05
I was confident in my responses to mission and ATC requirements	5.3	5.8	>.05

Pilot self-ratings of SA on six questions.





# Part Task Simulation 1



- Conclusions:
  - Potential benefits to both pilots and ATC when traffic information is provided in the Ground Control Station, even in positively controller airspace where ATC is responsible for separation
    - Largest benefit to pilots is increased SA
    - Improved ratings associated with Pilot-ATC comms/interactions
    - ATC rated UAS response as both timely and appropriate
- Future research needs to address ATC workload
  - Controllers rated workload with UAS as “somewhat higher” and separation and flow requirements rated as “slight more difficult”, compared to normal manned operations
  - Special handling procedures used 0-25% of the time



# Part Task Simulation 2



- Objectives:
  - Study the ability of a UAS operator to predict encounters with other aircraft and determine appropriate actions to ensure encounters are safe
  - Independent Variables:
    1. Level of Delegation
      - Extended:
        - ATC responsible for monitoring traffic and identifying potential conflicts
        - ATC alerts pilot of conflict and delegates solution identification and implementation to him/her
        - Both monitor resolution; pilot notifies ATC when clear of conflict
      - Full
        - Pilot is responsible for maintaining separation assurance
    2. Traffic display information
      - Basic (traffic only)
      - Advanced (traffic with conflict detection alerting based on ballistic information and use of the route assessment tool [RAT])
- Mission:
  - CO<sup>2</sup> emission monitoring in Southern California Center airspace
  - ATC maintains positive control over the sector; only UAS will be given delegated separation



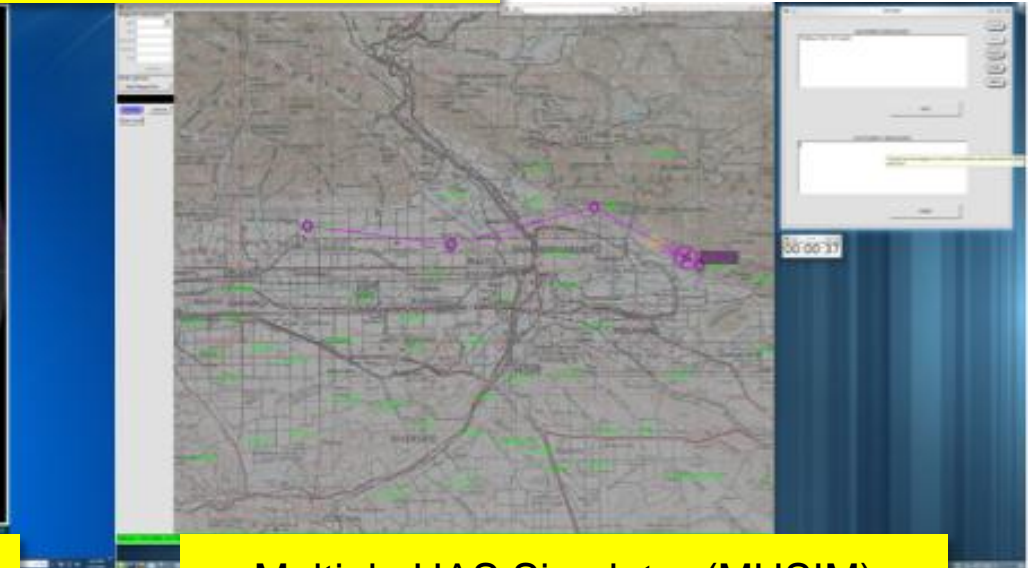
## Part Task Simulation 2

- Simulation Environment:
  - Ground Control Station: MUSIM and CSD with single GA pilot
    - CSD equipped with conflict detection and alerting and route assessment tool (RAT) in half of the trials
  - Pseudo Pilot Station: MACS (Multi Aircraft Control Station) with 1 pseudo-pilot
  - ATC Terminal: MACS with 1 retired controller

### Ground Control Station Set Up



Cockpit Situation Display (CSD)



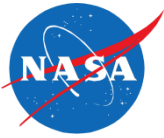
Multiple UAS Simulator (MUSIM)



## Part Task Simulation 2



- Dependent Variables:
  - Subjective:
    - Workload
    - SA
    - Preference & Usability
- Expected Results:
  - Air Traffic Controller
    - Reduced workload with higher delegation levels
    - Reduced radio communications with UAS in higher delegation levels
    - Less ATC interventions with UAS in higher delegation levels
  - UAS Operator
    - Increased (but manageable) workload with higher delegation levels
    - Increased SA with higher delegation levels

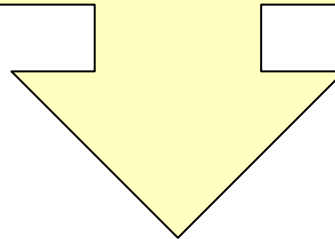


# Part Task Simulation 3

## LaRC Human-in-the-Loop (HITL) Experiments



- HITL01 = GCS Checkout and nominal line-of-sight operations  
(FY12Q4)
- HITL02 = Nominal operations with beyond-line-of-sight  
(FY14Q3)
- HITL03 = Non-normal operations (*e.g.*, lost link)  
(FY15Q3)



- Results will feed into:
  - (1) Flight Tests
  - (2) Information requirements
  - (3) CONOPS/Guidelines

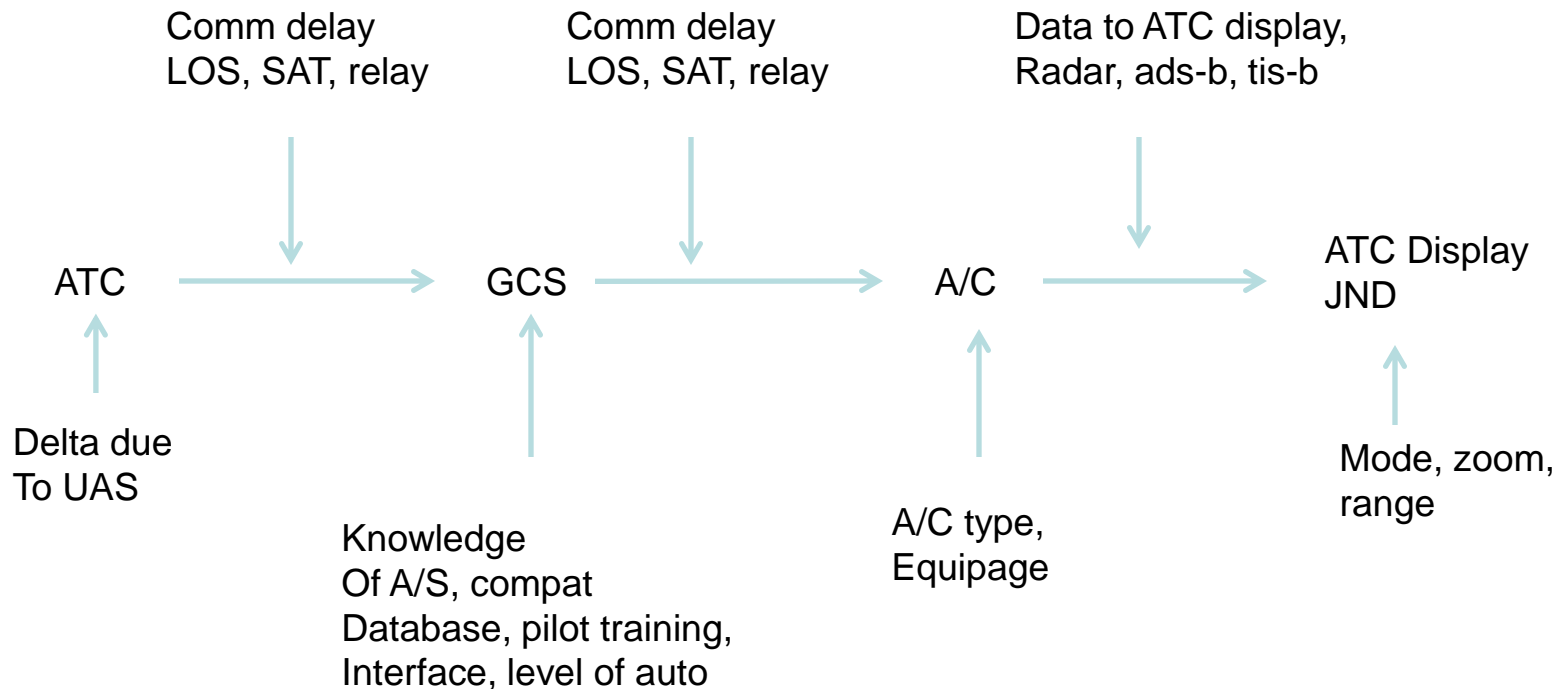


# Part Task Simulation 4

## Measured Response



- Is the UAS response to standard ATC commands acceptable ?
- Basic linear pattern – portions may/will iterate
- Not meant to be complete/comprehensive





# Part Task Simulation 4

## Measured Response



- Fall, 2012
- CSU-Long Beach
- MUSIM/ CSD/ MACS
- FAA/NASA Working group – bi-weekly meetings
- Test UAS response to set of ATC commands (from FAA)
- Proof of concept
- Methodology
- 4 Year plan to comprehensively investigate



# Part Task Simulation 5: Contingency Management



- Fall, 2012
- ARC
- Vigilant Spirit Control Station
- Contingencies:
  - Lost link
  - Engine out





## III. Develop recommendations for guidelines

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- Evaluated and chose appropriate standard organization
- SC 203
- Reviewed existing HSI guidelines
- Re-started dormant HF Group
- Alan Hobbs leading
- 45 members



# RTCA SC-203 UAS



- WG-1 Systems Engineering
  - WG 1.3 Human Factors
- WG-2 Control and Communications
- WG-3 Sense And Avoid (SAA)
- WG-4 Safety



# Human Factors Team Objectives

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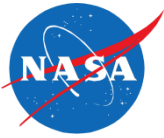
1. Input to workgroups  
(Ongoing)
2. Develop functional task analysis, Identify human role in each function –  
reference regulations for each/ flag where might need attention
3. Produce working paper containing guidelines (Mid 2013)



# Linkages to other Subprojects



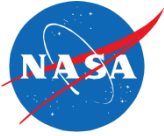
- Communications
  - Command and Control Datalink bandwidth
  - Datalink delays and variability
    - Satellite
    - Line of Sight
- Separation Assurance/Sense and Avoid Interoperability
  - Algorithms
  - Alerting logic
  - Roles and responsibilities
- Certification
  - Methods/issues for GCS certification
- Integrated Test and Evaluation
  - Data rates and accuracies
  - ADS-B



# Stakeholders & Partners



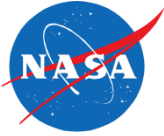
- FAA
- SC 203
- DoD
- AFRL – JOCA, Transit Ops
- Joint Warfighter Advisory Group (JWAG)
- Air Force Reserve (Beale)
- Navy – BAMS
- CSU - Long Beach
- University of Illinois
- CSU - Northridge
- NATO - HFM



# Summary



- Strong team in place
- Excellent Facilities
- Good coordination with academia, FAA, other government
- Multiple – complementary information requirements underway
- State of Art assessment (GCS Catalog) underway
- Good communication between subprojects
- Excellent progress on multiple part-task simulations



# Questions?

*Jay Shively (Ames)*

*[Robert.J.Shively@nasa.gov](mailto:Robert.J.Shively@nasa.gov)*



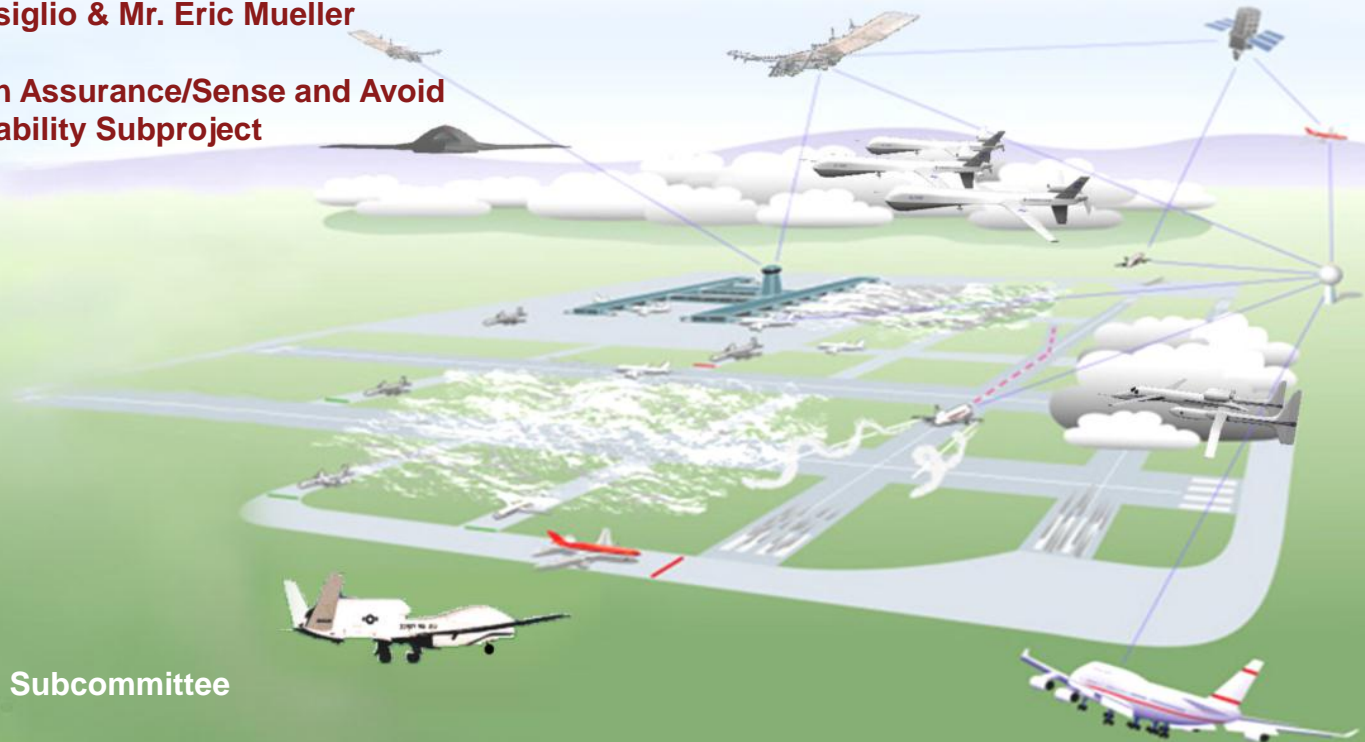
National Aeronautics and Space Administration



# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

**Presented by: Ms. Maria Consiglio & Mr. Eric Mueller**

**Project Engineers, Separation Assurance/Sense and Avoid  
Interoperability Subproject**



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 28, 2012





# Presentation Outline

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- Airspace Integration Challenges for UAS
- Objectives
- Technical Approach
- Accomplishments
- Linkages to other Subprojects



# Separation Assurance/Sense and Avoid Interoperability



FY	Technical Activity
FY12	Development of concepts for integrating UAS with the NAS
FY13	Fast-time assessment of UAS-NAS integration concepts
FY14	SSI Human-In-The-Loop simulation assessment
FY15	Integrated Flight Test Series 3
FY16	Integrated Flight Test Series 4

## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Airspace Integration Challenges for UAS



- No onboard pilot to perform the see-and-avoid function
  - UAS sense and avoid (SAA) interoperability with the NAS
- Aircraft performance
  - Climb and descent rates, cruise speeds, turn rates atypical
- Missions
  - Loitering may create different per-aircraft impact on airspace
  - Different mission objectives than “getting to point B”
- Communications
  - Latencies affect voice communication and maneuver responses
  - Lost-link conditions present unique challenges
    - SAA autonomy
    - Predictability

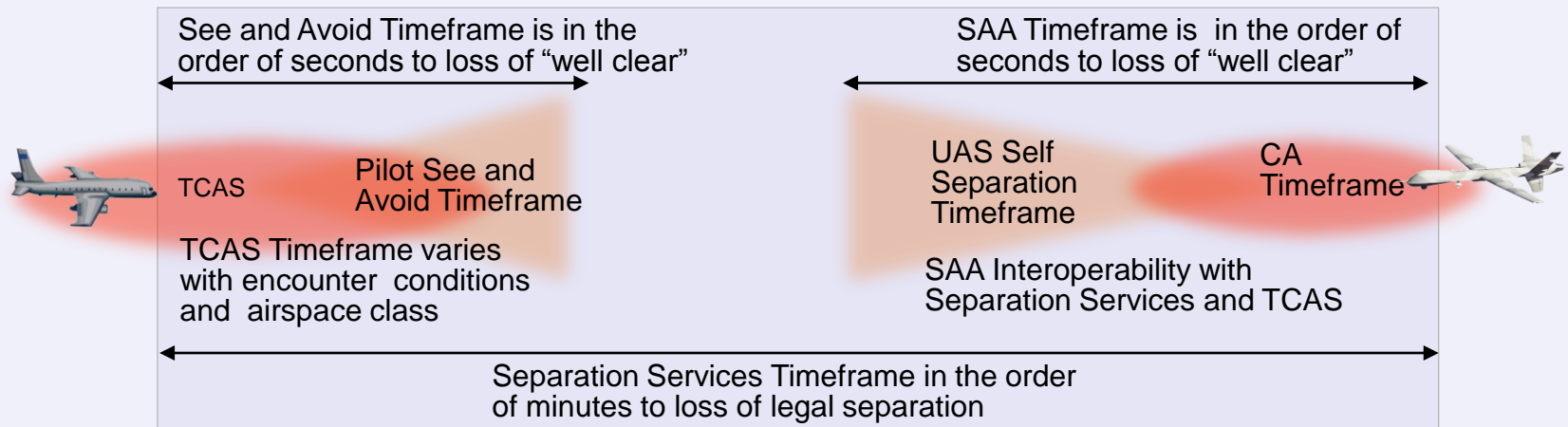


# Airspace Integration Challenges for UAS

- The lack of an onboard pilot leads to the problem of how to deal with the legal requirement identified in the US Code of Federal Regulations (CFR) that pilots “see and avoid” other aircraft (specifically 14 CFR 91.113)

Sense and Avoid (SAA) was defined by the FAA sponsored SAA for UAS Workshop Final Report published in October 9, 2009 as “the combination of UAS Self-Separation (SS) plus Collision Avoidance (CA) as a means of compliance with 14CFR Part 91, § 91.111 and § 91.113”

## UAS Interoperability with existing systems and separation services



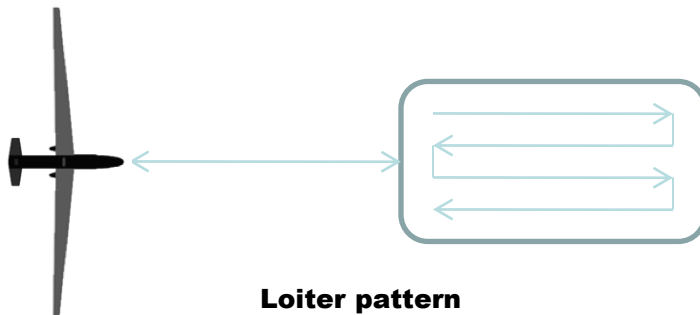
Notional depiction of Sense and Avoid (SAA) timeframes of applicability

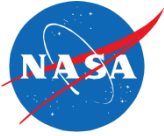
# Airspace Integration Challenges for UAS

- Aircraft performance
  - Climb and descent rates, cruise speeds, turn rates atypical



- Missions
  - Loitering may create different per-aircraft impact on airspace
  - Different mission objectives than “getting to point B”

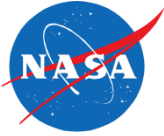




# Airspace Integration Challenges for UAS



- Communications
  - Command and control communications between the UA and GCS may be affected by link latency
  - Relayed voice communications from/to ATC facilities and proximate “party-line” aircraft may be affected by the link performance (e.g., link latency, availability, etc.). Possible impact on:
    - Air traffic controllers
    - Pilots of manned aircraft
    - GCS operator
  - Lost-link conditions present unique challenges
    - SAA autonomy
    - Predictability



# Presentation Outline

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- Airspace Integration Challenges for UAS
- Objectives
- Technical Approach
- Accomplishments
- Linkages to other Subprojects



# SSI Subproject Objectives



Assess the interoperability of UAS sense-and-avoid systems with the ATC environment

Assess the effects of UAS mission and performance characteristics, communications latencies and changes to separation roles and responsibilities on the NAS





# Presentation Outline

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- Airspace Integration Challenges for UAS
- Objectives
- Technical Approach
- Accomplishments
- Linkages to other Subprojects



# SSI Technical Approach



- Define UAS-NAS integration concepts as a function of available technologies or capabilities
  - MidGen, assuming only *expected* FAA Operational Improvements through ~2016
  - NextGen, as defined in the FAA's Enterprise Architecture and by NASA research
- Evaluate NAS impact of UAS operations in fast-time simulation
  - Study mission, performance, communication, separation responsibility
  - Evaluate UAS-SAA performance tradeoffs
  - Assess impact of SAA system on the NAS
- Conduct human-in-the-loop simulations
  - Collect human performance metrics not obtained in fast-time simulation
- Conduct integrated human-in-the-loop simulations
- Conduct integrated flight tests



# First NASA-FAA Workshop



## Important Airspace Integration Questions Developed during the NASA-FAA Workshop in December 2011

- What are the performance expectations (requirements) for UAS envisioned to equip with Sense and Avoid equipment (e.g., performance envelope, maneuvering requirements)?
- What are the effects (capacity, workload, efficiency) of sense-and-avoid solutions on the ATC environment (e.g., what is the impact on ATC workload of a large number of UAS in non-segregated airspace)?
- Does the inability to accept visual separation clearances degrade the capacity or efficiency of operations or increase controller workload by limiting options available to delegate separation authority in various airspaces?



## Second NASA-FAA Workshop



Three broad areas of research have been identified to contribute to some of the UAS integration challenges as briefed to the FAA in March 2012:

1. UA ↔ SAA performance tradeoff assessments
2. NAS-wide assessments of UAS impact on airspace capacity/efficiency/safety
3. Controller-in-the-loop assessments of SAA-equipped UAS in ATC environment

These research thrusts comprise different but linked studies and experimental activities addressing a subset of specific problems included in the research questions



# Presentation Outline

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- Airspace Integration Challenges for UAS
- Objectives
- Technical Approach
- **Accomplishments**
- Linkages to other Subprojects



# Current SSI Activities

**SSI**

**Assess the interoperability of UAS sense-and-avoid systems with the ATC environment**

**Assess the effects of UAS mission and performance characteristics, communications latencies and changes to separation roles and responsibilities**

**UAS Integration Concepts**

**SAA Use Concept**

**Fast time studies**

**UAS-SAA Performance tradeoffs**

**Controller-in-the-loop simulation experiments**

**HITL Simulation Platform Enhancements**

**Visual operations experiments**

**UAS Integration Concepts**

**SA NAS Concept**

**Fast time studies**

**NAS-wide performance impact evaluations**

**Evaluation of SA Algorithms**

**Controller-in-the-loop simulation experiments**

**Visual operations experiments**



# Development of Concepts for UAS-NAS Integration



**An interoperability concept for SAA is under development that uses as its foundation the following SAA implementation principles:**

- SAA's "Well Clear" separation large enough to avoid:
  - Corrective RAs for TCAS-equipped intruders
  - Traffic alert issuances by controllers
  - Undue concern for proximate see-and-avoid pilots
- SAA's "Well Clear" deviations small enough to avoid disruptions to traffic flow and vary appropriately with:
  - Encounter geometry
  - Operational area (airport vicinity, en route, etc.)

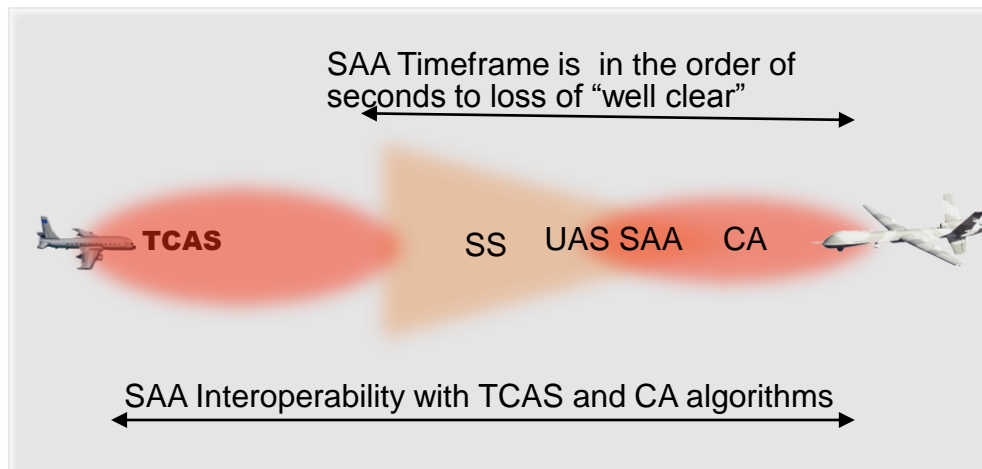


# Development of Concepts for UAS-NAS Integration



## SAA interoperability implementation principles (cont.)

- SAA's threat declaration times small enough to avoid nuisance queries and large enough to allow
  - Query/negotiation with controller (if receiving services)
  - Normal/operational maneuvers as required
- TCAS-compatible SAA's collision avoidance maneuvers (if/when detection occurs too late for self-separation)







# Development of Concepts for UAS-NAS Integration



How do UAS-specific missions, performance, communications and SAA factors affect the capacity, safety and efficiency of the NAS?



UAS Operator at the Ground Control Station



Unmanned Aircraft



Controller

Five important components to the concept:

- Who detects and resolves conflicts?
- What information is required for conflict detection and resolution?
- What coordination is required for conflict resolution?
- Under what circumstances does responsibility change?
- Should qualitative regulations be quantified?

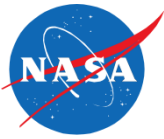


# Separation Assurance/Sense and Avoid Interoperability (SSI)



## UA ↔ SAA Performance Tradeoff Assessments

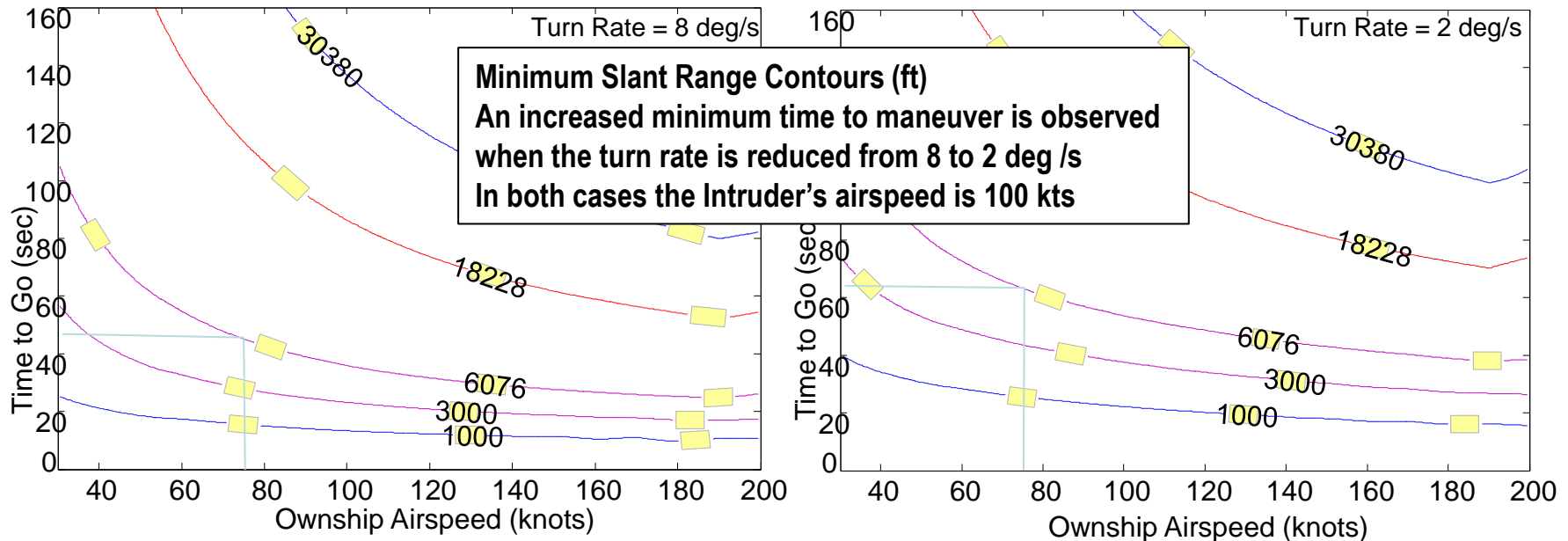
- A series of batch (non-human-in-the-loop) simulation experiments designed to determine the interaction of UAS and SAA system performance requirements are being designed
- Experiments will be based on a range of diverse UA (unmanned aircraft) with present and future aerodynamic performance and maneuverability, sensor performance, and maneuver selections
- Results from these experiments are expected to support design guidelines and requirements development for SAA concepts and technologies both for regulators and UAS designers



# Separation Assurance/Sense and Avoid Interoperability (SSI)



## UA ↔ SAA Performance Tradeoff Assessments



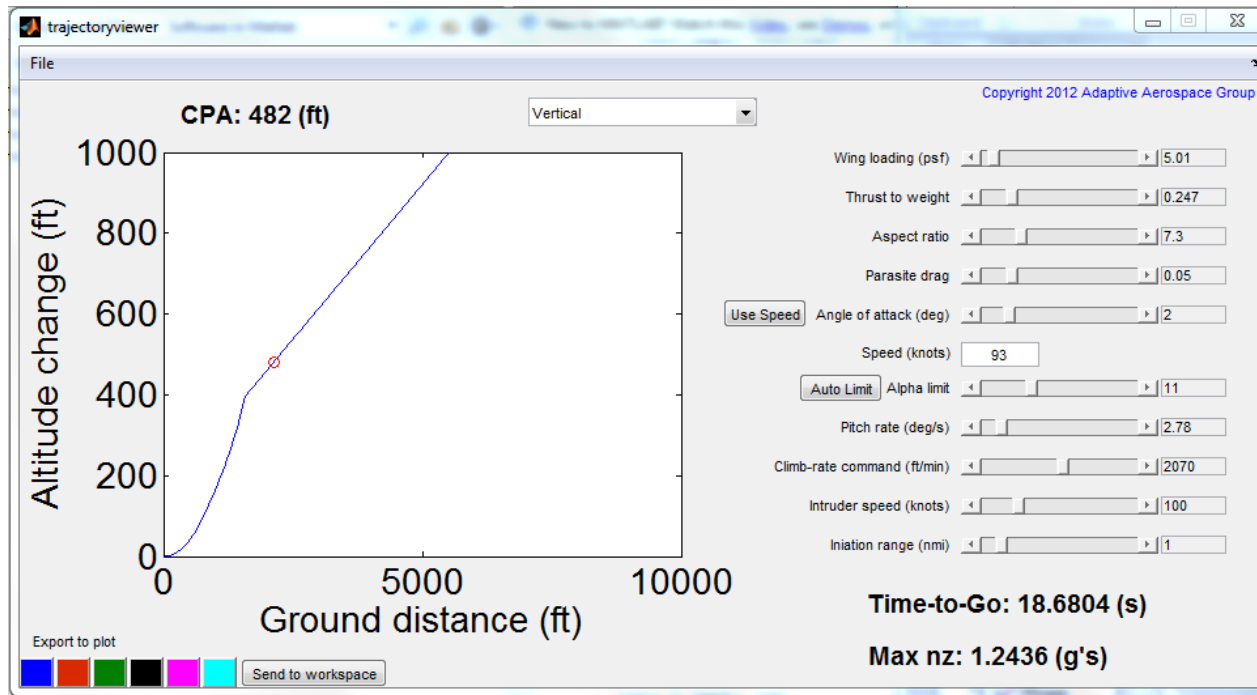
- The Prototyping Aircraft-Interaction Research Simulation (PAIRS) tool is a simulation environment with a configurable 6DOF (Degrees-of-Freedom) performance model
- Preliminary results showing the impact of turn rate on initial SAA time-to-go on closest point of approach.
- Increasing turn rate from 2 deg/sec to 8 deg/sec for a UAS cruising at 75 knots reduces time-to-go requirements for SAA maneuver initiation by ~30% if 1 nmi is declared to be required separation.



# Separation Assurance/Sense and Avoid Interoperability (SSI)



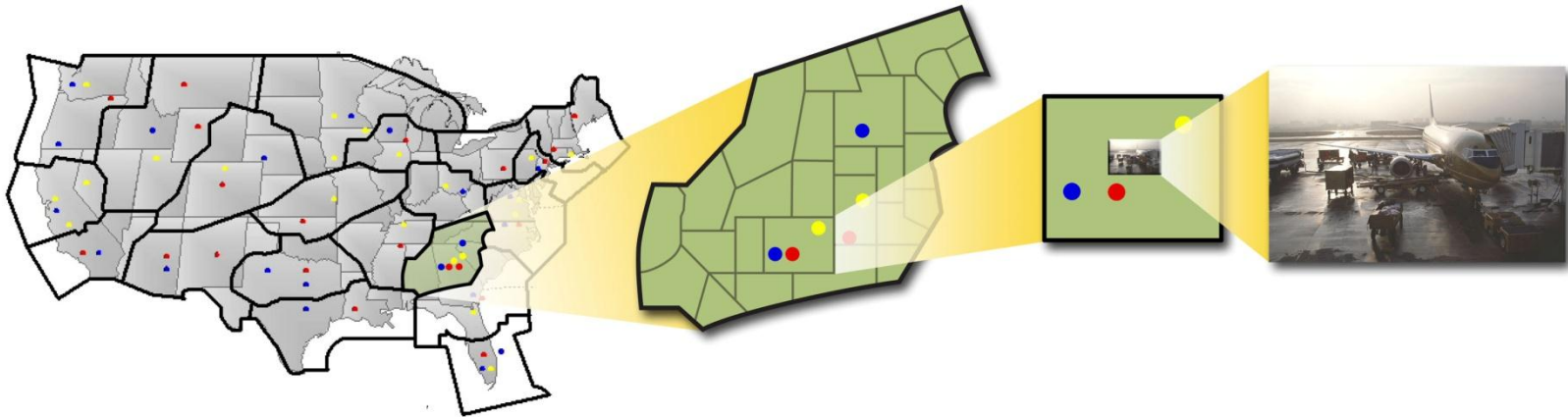
- A new interactive tool (based on PAIRS) was developed to allow real time observation of the impact of vertical and horizontal maneuver performance on pair-wise encounters of two aircraft.
- The GUI based tool also allows the user to plot up to 6 cases on one figure and output results to a Matlab workspace for detailed analysis.



- The simulated scenario consists of two aircraft initialized co-altitude, on a collision course.
- The intruder aircraft is at 1 nmi and 18.7 seconds from the ownship flying at 100 knots.
- The ownship immediately climbs to avoid the collision.
- The CPA (closest point of approach) occurs at 482 ft.



# NAS-wide Fast-Time Simulation Capability: Airspace Concept Evaluation System



## National Traffic Management

Nationwide gate-to-gate simulation of ATM operations

Full flight schedule with flight plans

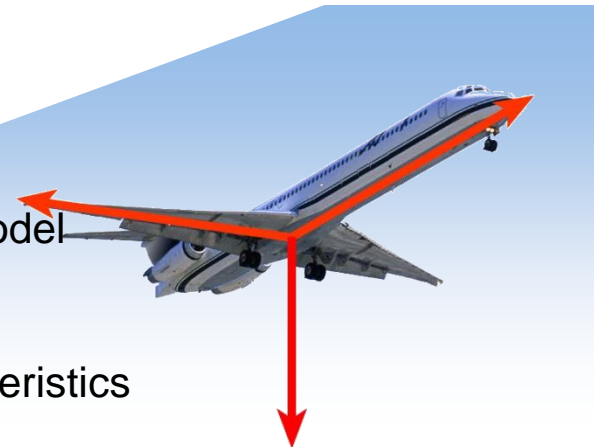
## Simulation Agents

Air traffic controller decision making

Traffic flow management models

Individual aircraft and airline preferences

Medium Fidelity 4-DOF Trajectory Model  
Aerodynamics models of aircraft  
Models replicate pilot behavior  
User-definable uncertainty characteristics



# Example Fast-Time Simulation Experiment

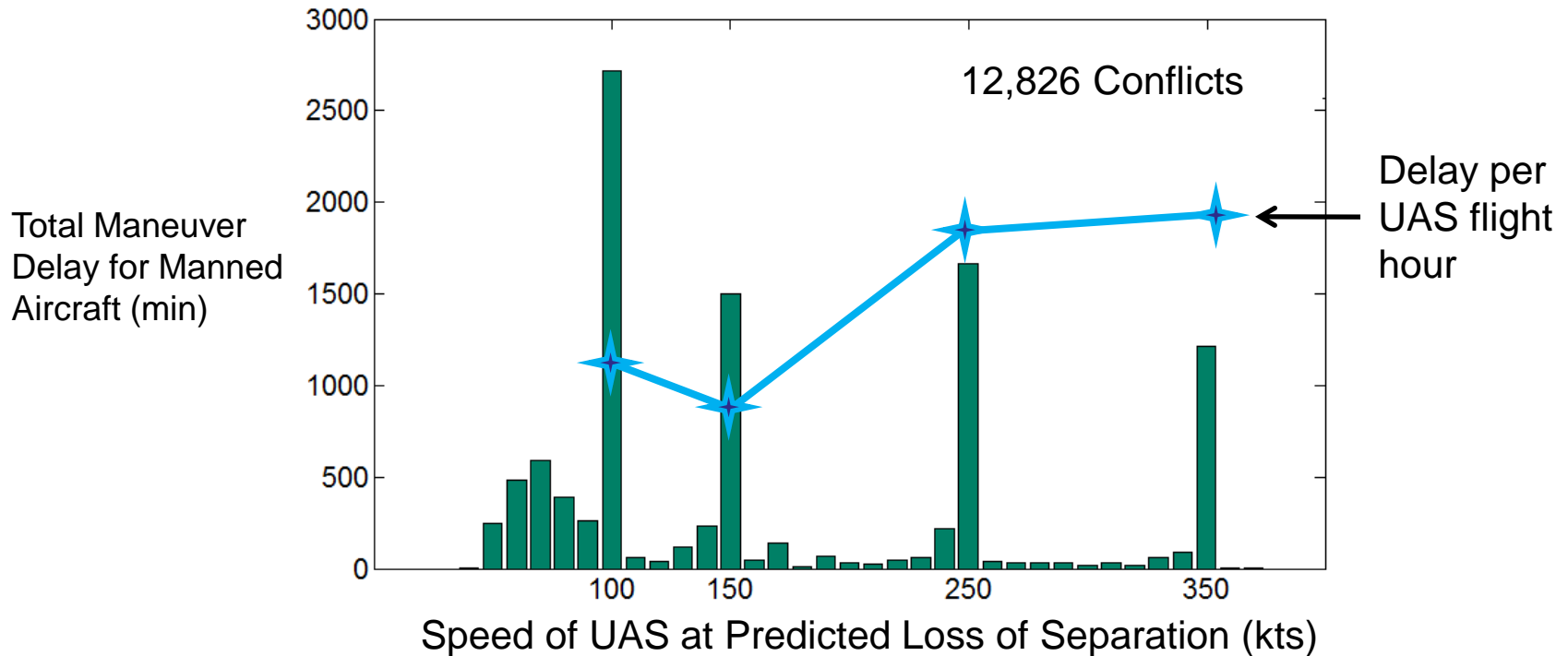
- Research questions
  - How does speed and altitude of UAS affect the delay to existing traffic?
  - What approaches are effective at mitigating the impact of UAS?
- Scenario
  - Background traffic from June 7 – 9, 2011
  - UAS models similar to MQ-9 and RQ-4
- Independent Variables
  - Cruise altitude of UAS
  - Cruise speed of UAS
  - Horizontal separation requirement
  - Responsibility for conflict resolution (“burdened aircraft”)
- Metrics
  - Number of conflicts caused by UAS
  - Conflict resolution delay incurred by existing traffic



UAS Missions

# Delay by UAS Speed

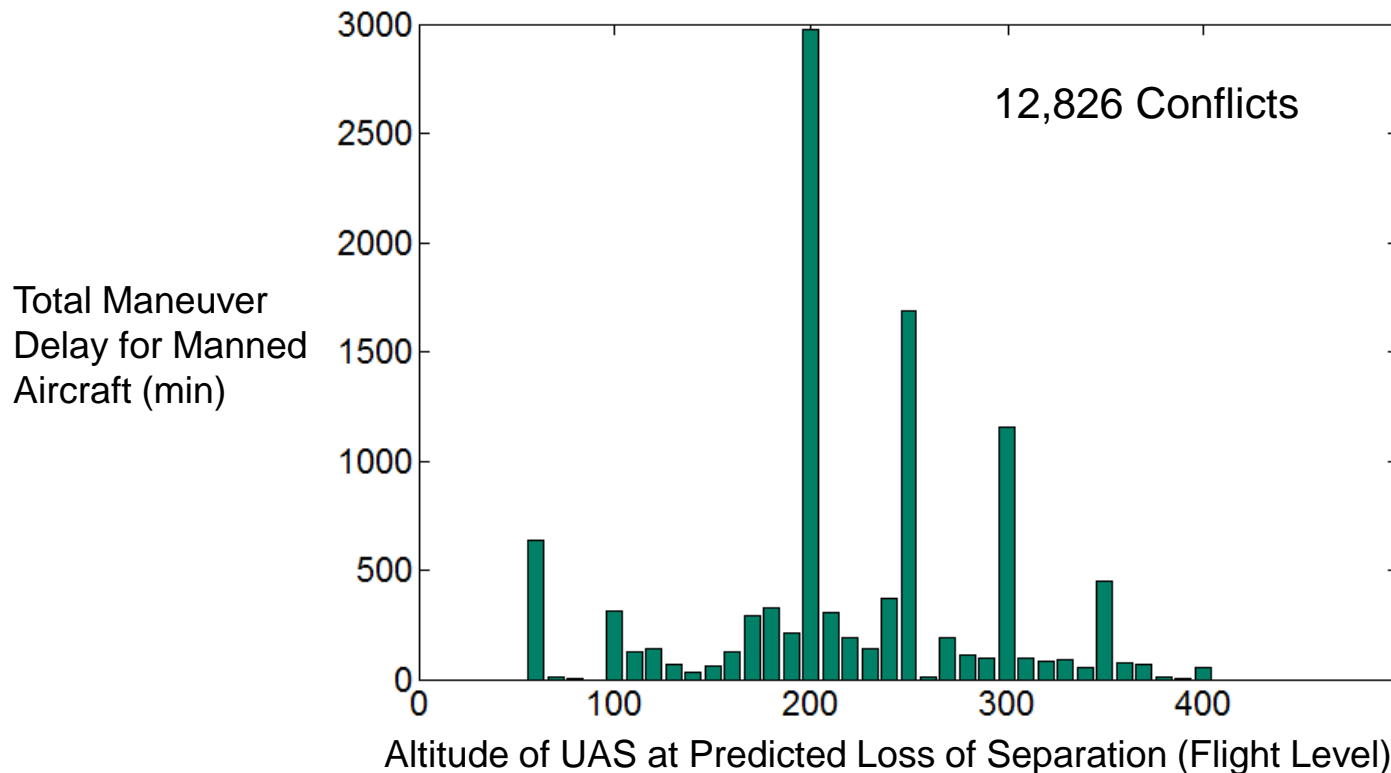
Resolution delay for manned aircraft by UAS speed



Less delay per UAS flight hour at lower speeds

# Impact by Altitude

Resolution delay for manned aircraft by UAS altitude



Most delay per UAS at low altitudes and while transitioning

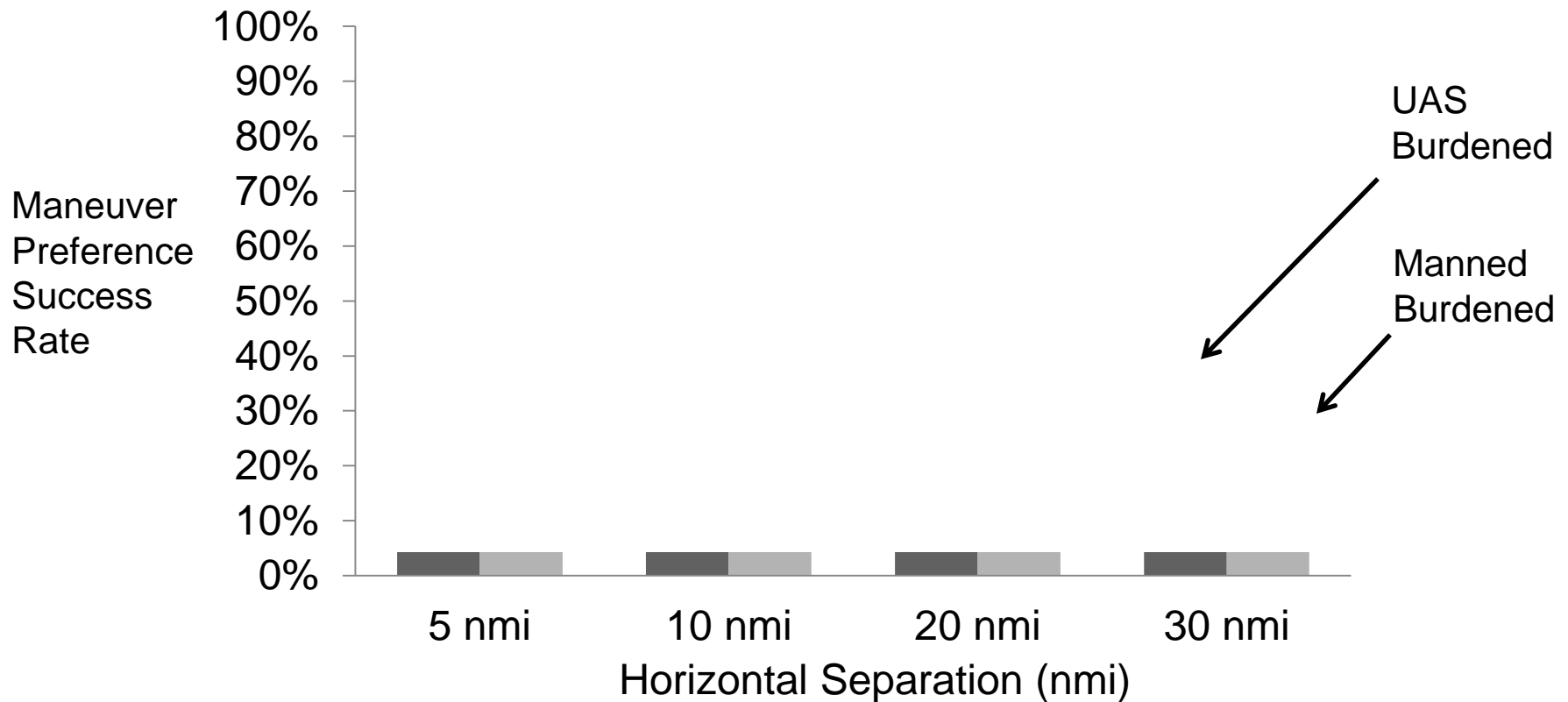




# Reducing the Impact of UAS on Existing Traffic



- Require larger horizontal separation distances for UAS
- Require UAS to resolve conflicts, if possible



Poor UAS performance forces manned aircraft to resolve conflicts



# Controller-in-the Loop Assessments



**Human-in-the-loop simulation experiments are under development to measure ATC impact of SAA equipped UAS**

**Rationale:** SAA algorithms may recommend different (larger, smaller, earlier, later) maneuvers than those that might be executed by a manned aircraft pilot in the same situation. SAA technologies may have greater or lesser detection range and accuracy compared to visual target acquisition.

## **Research questions:**

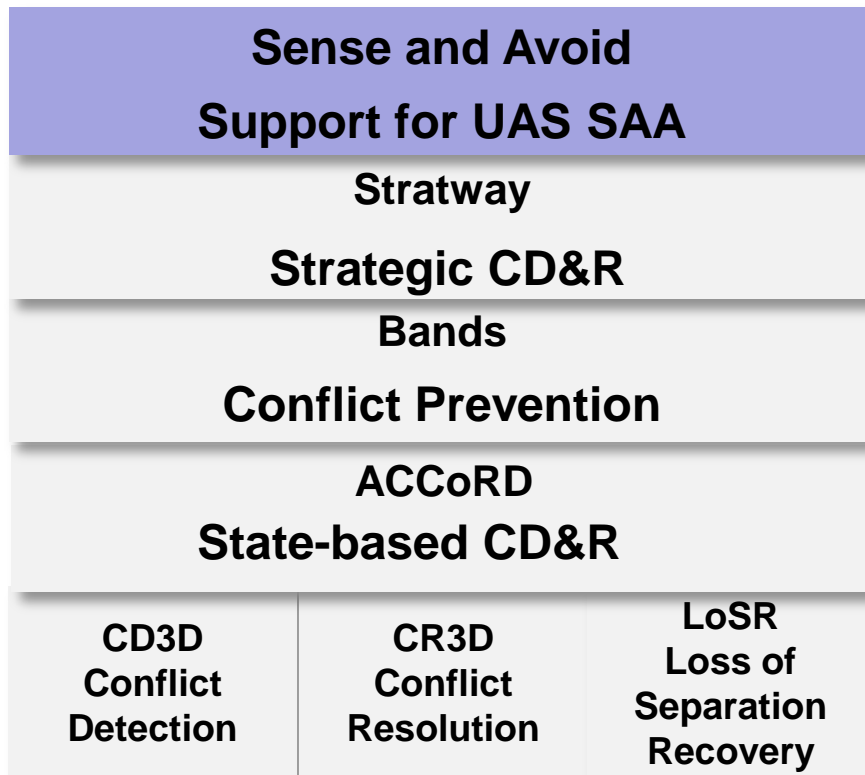
- What maneuvers are too small or too late, resulting in conflict alerts or controller perceptions of unsafe conditions?
- What maneuvers are too large (excessive “well clear” distances), resulting in behavior the controller would not expect and/or disruptions to traffic flow?
- What maneuvers are directed too early by SAA, resulting in excessive or unnecessary pilot requests to ATC for deviations?
- What is the impact on the NAS of a UAS with an inability to comply with visual clearances?



# Separation Assurance/Sense and Avoid Interoperability (SSI)



## Modification of NASA's SA algorithms to support SAA interoperability concept and integration experiments



SAA algorithm modification involved analysis and implementation of a separation criteria compatible with existing collision avoidance technology ( i.e., TCAS)

Existing software capability comprises algorithms for SA that are being extended to implement UAS specific applications

All algorithms have been *formally verified* and satisfy implicit criteria-based coordination.



# Separation Assurance/Sense and Avoid Interoperability (SSI)



## Integration and Evaluation of SAA Algorithms

### Jointly Optimal Collision Avoidance Algorithm

Integrated into the PAIRS (Prototyping Aircraft-Interaction Research Simulation) tool

Integration enables the evaluation of the impact of vehicle performance on CA maneuvers

Effort to integrate into ACES (Airspace Concept Evaluation System) underway

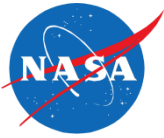
Integration may enable the evaluation of the impact of CA maneuvers on the airspace

Initial evaluation for integration with MACS (Multi Aircraft Simulation System) completed

Integration would enable the evaluation of a full JOCA based SAA solution with controllers/pilots in the loop experiments

JOCA is an AFRL developed conflict avoidance algorithm initially developed for autonomous application. It is continuously evolving in association with specific aircraft.

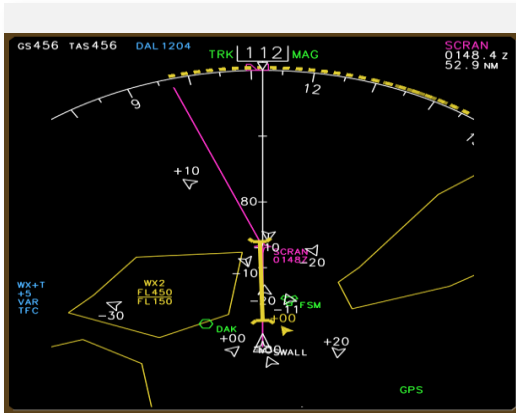
Extensions of the understanding of its suitability for use on a wide range of UAS and for use with operators in the loop are needed to address integration with other systems and the possibility of near term use in the NAS.



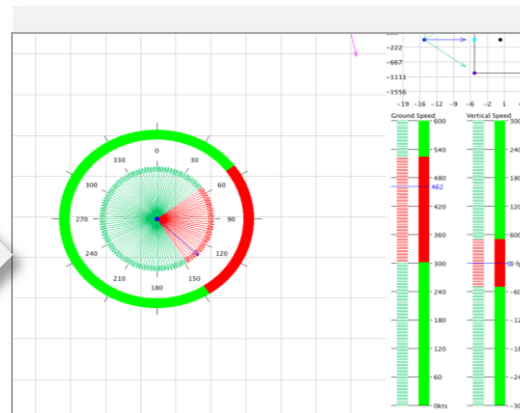
# Separation Assurance/Sense and Avoid Interoperability (SSI)



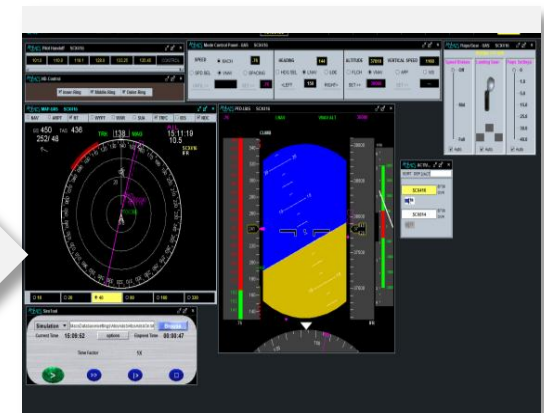
## Adapting NASA's Experimental SA Alerting Displays to support UAS Integration



Conflict alerting bands are implemented as part of a prototype airborne separation assurance tool known as the Autonomous Operations Planner (AOP) currently being evaluated by NASA



Alerting logic is being adapted for UAS SAA display applications as a pilot advisory tool. Pilot procedures for UAS SAA operations are also being developed.



UAS Ground Control Station with Experimental SAA Interface includes prevention "no fly" bands to advise the pilot in control of potential intruders

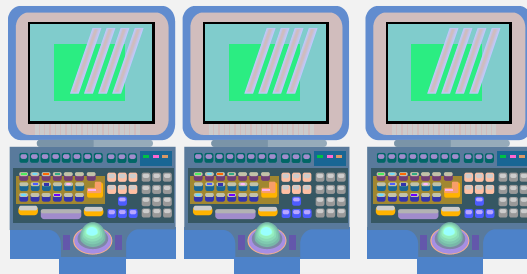
Adapting the experimental SA displays to support UAS ground station pilot procedures involves an effort that spans SAA algorithms, air traffic operations, pilot procedures, displays design and human factors considerations.



# Separation Assurance/Sense and Avoid Interoperability (SSI)

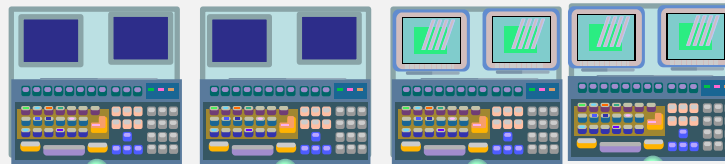


MACS-UAS: Multi Aircraft Control System Simulation Platform Adapted for UAS Human in the Loop Experiments



ATC Stations

## UAS HITL Simulation Platform



Pseudo-Pilot Stations

Ground Control Stations

Gateway

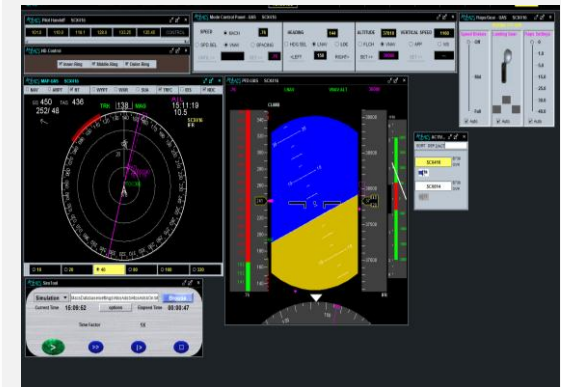
- Other Lab Facilities
- High Fidelity Simulators



ATC Station



Pseudo Pilot Station



UAS Ground Control Station with Experimental SAA Interface

MACS Software modifications underway: Surveillance and Communications for UAS research. UA vehicle performance integration. Implementation of SAA pilot interface and adaptation of the pseudo-pilot station to implement the GCS.



# Presentation Outline

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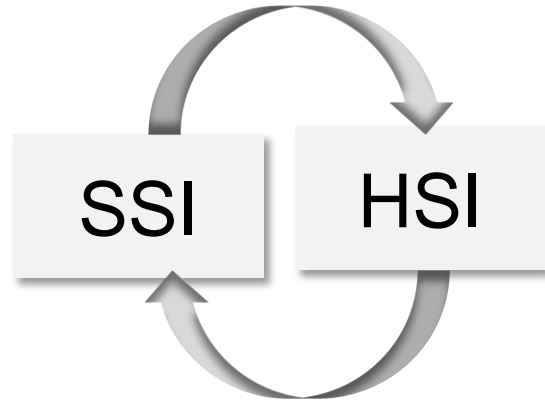


- Airspace Integration Challenges for UAS
- Objectives
- Technical Approach
- Accomplishments
- Linkages to other Subprojects



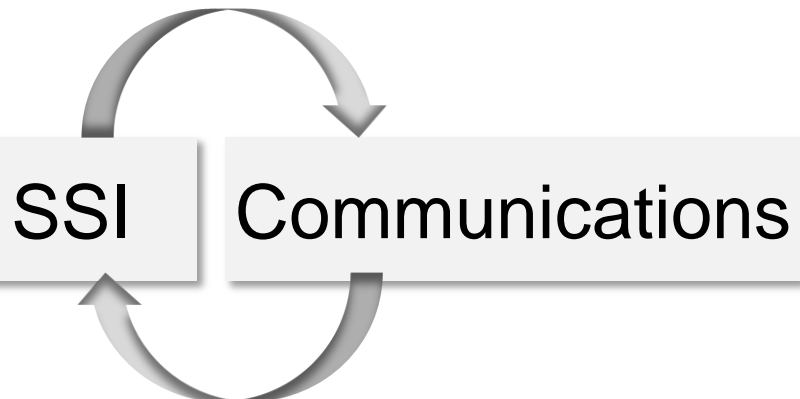
# Linkages to other Subprojects

- SAA Display Requirements for GCS
- SAA concept of use
- Operator-ATC communications requirements
- SAA Algorithms



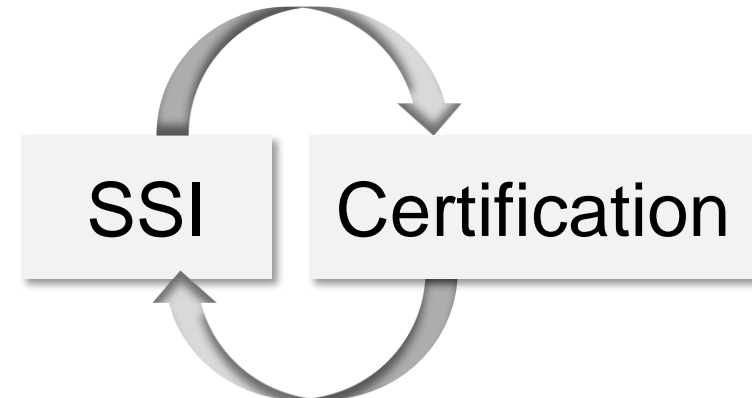
- Human factors considerations for SAA interface and pilot procedures
- GCS

- SAA algorithms



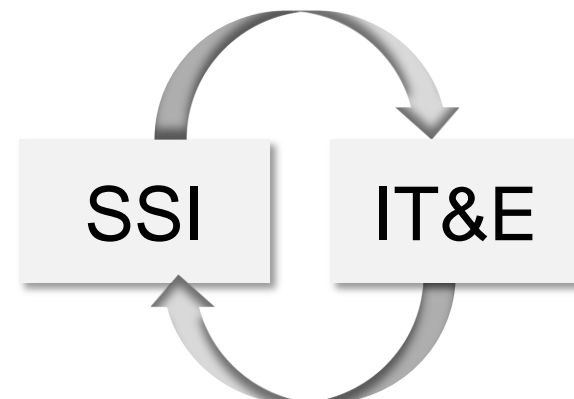
- Communications latencies and delays

- SAA concepts and procedures. Mission Scenarios



- Safety impact and certification options and implications
- Airworthiness requirements

- SAA and SA Algorithms and Displays



- Results from integrated tests





# Partnerships and Collaborations



**A substantial part of the SSI work underway is the result of a close NASA-FAA collaboration that began in December 2011.**

**A UAS NASA-FAA research team was recently formed to support this interaction and ensure alignment of objectives is maintained.**



**Contributed to the JPDO R&D Roadmap on SAA and plan to continue as needed**



**AFRL developed algorithms are part of the suite of SAA capabilities under consideration**



**Several members of the SSI team are actively involved with SC203 SG3 and ad-hoc committees on SAA and Modeling and Simulation**





# Partnerships and Collaborations

## NASA Research Announcements and SBIR Contracts





# Separation Assurance/Sense and Avoid Interoperability (SSI)



Thank You for Your Attention

Questions

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*Eric Mueller (Ames)*

*[Eric.R.Mueller@nasa.gov](mailto:Eric.R.Mueller@nasa.gov)*



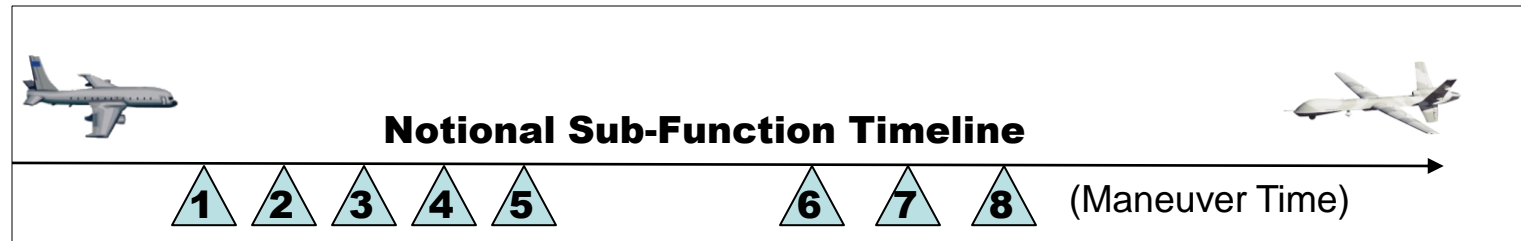
# Separation Assurance/Sense and Avoid Interoperability (SSI)

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Back up slides

## SAA Interoperability Concept: Sub-Functions and Allocation



1. **Detect** intruder
2. **Track** intruder (position & velocity)
3. **Evaluate** (assess collision or self-separation risk)
4. **Prioritize** intruder risks
5. **Declare** that some action may be required
6. **Determine** what action(s), if any, to take
7. **Command** determined action, if any
8. **Execute** commanded action

These Sub-Functions performed by sensors and algorithms, with traffic information elements/decision aids displayed to the GCS pilot

GCS pilot evaluates info elements, queries or responds to ATC as necessary, commands action if needed

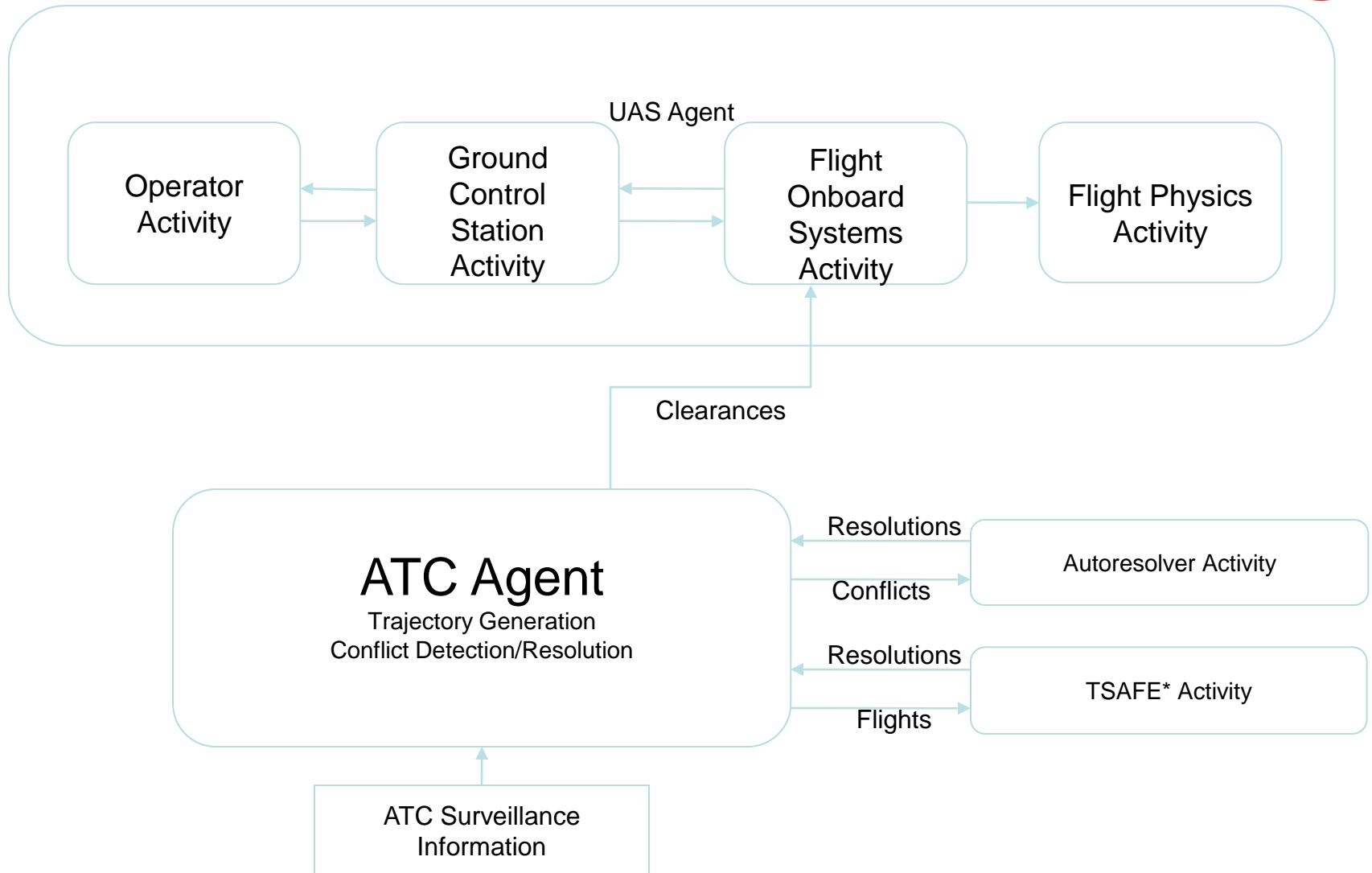
Action executed by UA systems

If late detection leaves insufficient time for ATC coordination and a maneuver is necessary for safe separation, the pilot may maneuver first and then inform ATC (same as a see-and-avoid pilot)

If lost link is detected by the UA, Sub-Functions 6 & 7 **may** be autonomously performed, at the CA threshold or possibly earlier (TBD)



# Fast-Time Simulation Architecture



**\*TSAFE = Tactical Separation-Assured Flight Environment**



National Aeronautics and Space Administration



# Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

**Presented by: Mr. Jim Murphy and Mr. Sam Kim**

**Project Engineers, Integrated Test & Evaluation Subproject**



NASA Advisory Council  
Aeronautics Committee, UAS Subcommittee  
June 28, 2012



# IT&E Outline



- Project Technical Challenges/Subproject Milestones
- Objectives
- Technical Approach
- Accomplishments
- Linkages to other Subprojects
- External Connectivity





# Integrated Test and Evaluation



FY	Technical Activity
FY12	Integrated Human-In-The-Loop and Flight Test Concept and Objectives development
FY13	Live Virtual Constructive – Distributed Environment development/evaluation
FY14	Integrated Human-In-The-Loop simulation
FY15	Integrated Flight Test Series 3
FY16	Integrated Flight Test Series 4

## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Integrated Test & Evaluation



- Objectives
  - Define and develop infrastructure that will create operationally relevant environments that is adaptable and scalable to incorporate the concepts and technologies to be evaluated by the SSI, Communications, HSI, and Certification subprojects
  - Employ systems level integrated simulations and flight tests to validate models, assess system interactions, and determine the effectiveness of the concepts and technologies at reducing the technical barriers associated with routine UAS access into the NAS



# Integrated Test & Evaluation



- Approach
  - Document candidate test environment and known requirements
  - Build a Live, Virtual, Constructive distributed environment (LVC-DE) to provide the basic relevant environment in anticipation of the sub-project requirements
  - Tailor LVC-DE to meet specific Simulation and Test requirements
- The LVC-DE is the tool to be used to provide the relevant environment for the integrated events



# Integrated Test and Evaluation

FY	Technical Activity
FY12	Integrated Human-In-The-Loop and Flight Test Concept and Objectives development
FY13	Live Virtual Constructive – Distributed Environment development/evaluation
FY14	Integrated Human-In-The-Loop simulation
FY15	Integrated Flight Test Series 3
FY16	Integrated Flight Test Series 4

**Document**

**Build**

**Tailor**

**Tailor**

**Tailor**

## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Relevant Test Environment



- An adaptable, scalable, and available relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS
- Level of fidelity depends on the specific scenario and simulation outcome measures
- Relevant environment, not necessarily real/operational environment





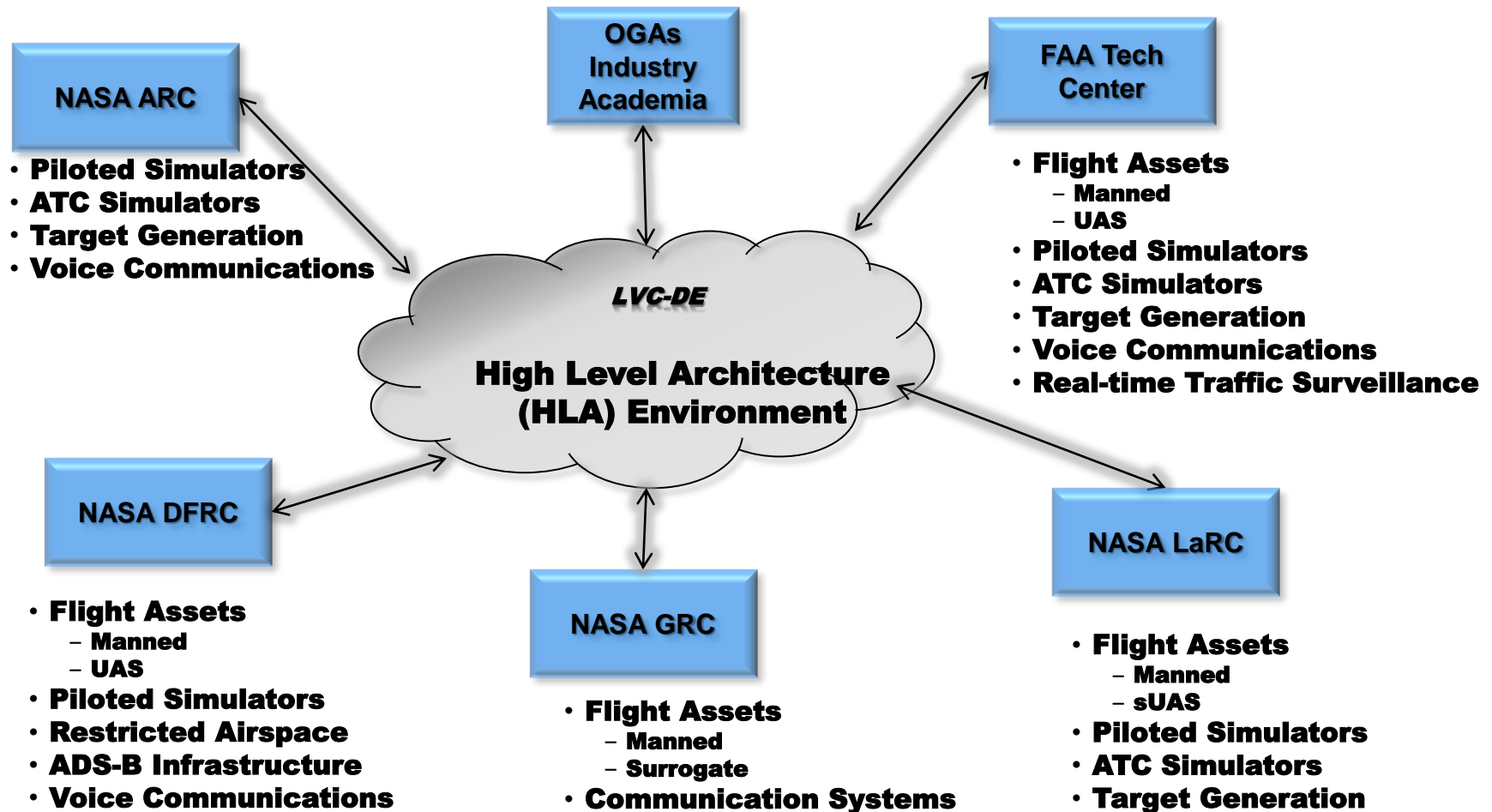
# Technical Activity: Document



- Integrated Human-In-The-Loop and Flight Test Concept and Objectives development
  - Test Objectives define what is needed for a relevant environment
  - Test Concept is our response to deliver a relevant environment
  - Document the high level objectives of the HITL Simulations and Flight Tests and the how we plan to test those objectives
    - The summary document is intended to be disseminated to a wide audience to inform both internal and external partners of the Project Test Plans
    - The detailed document provides additional description of test resources and infrastructure to facilitate technical integration amongst sub-projects



# Notional Simulation and Flight Test LVC-DE



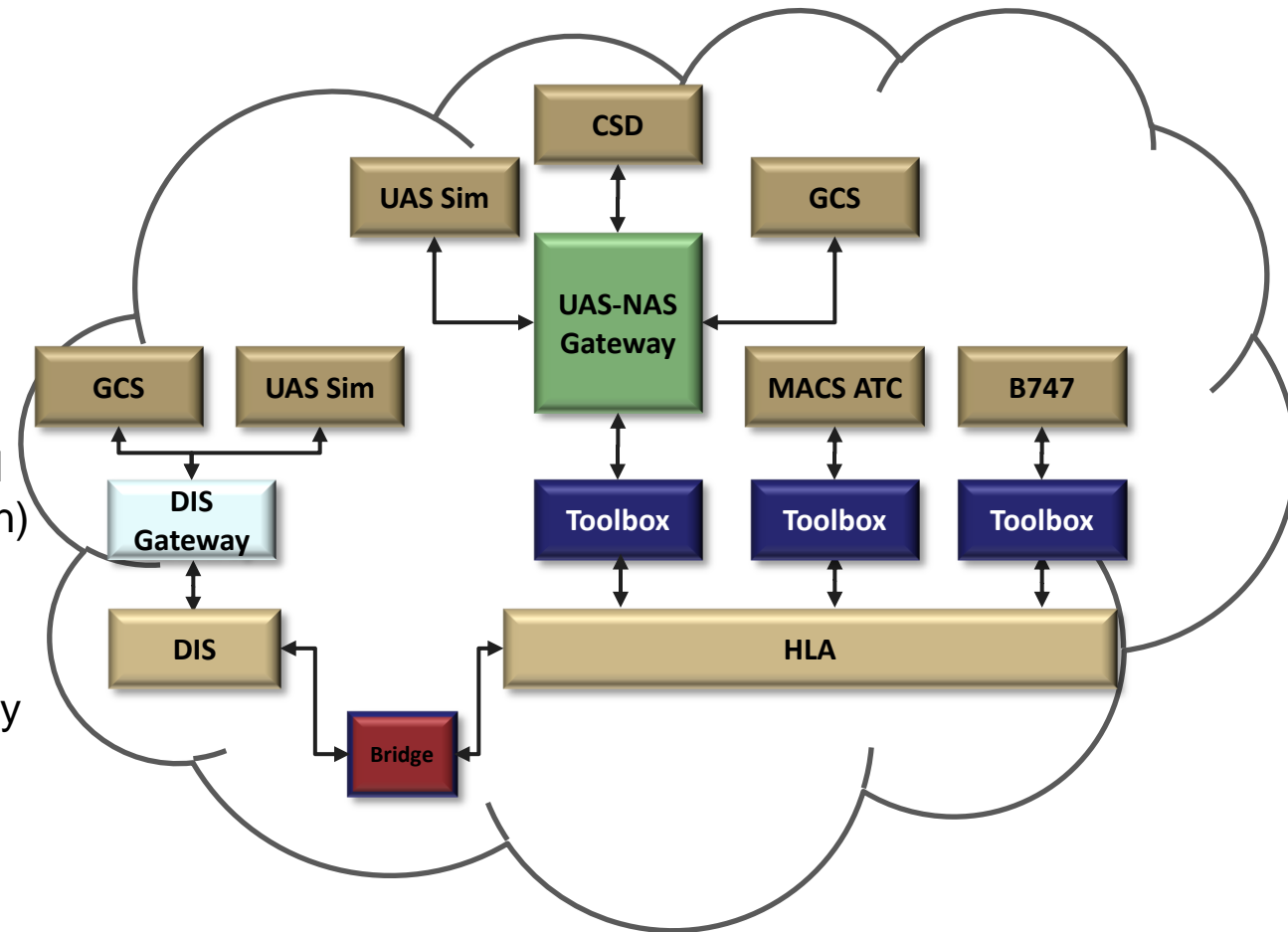
Build test environment based on existing capabilities wherever they exist



# LVC-DE Essentials

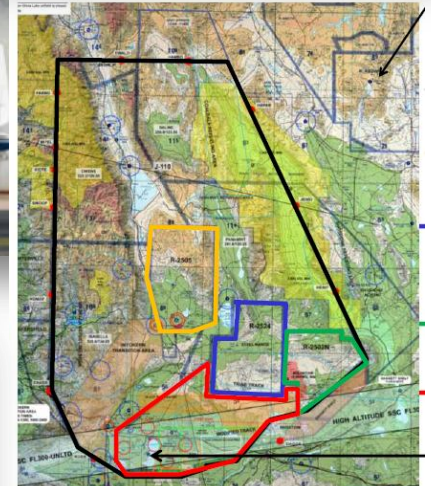


- External Connectivity
  - VPN, NASA Integrated Services Network (NISN), Defense Research and Engineering Network (DREN), Internet
- Architectural Middleware
  - HLA/DIS (Distributed Interactive Simulation)
  - Bridge
- Simulation Interface
  - Toolbox/DIS Gateway
  - Device Gateway
- Participant Devices
  - Cockpit, GCS, Displays, etc.





- Unmanned aircraft
  - Ikhana equipped with ADS-B
    - Tested ADS-B in and out
  - Global Hawk
  - DROID
- Surrogate aircraft
  - T-34C for Comm and integrates SSI algorithms
  - TG-14
- GCS equipage
  - CSD with the Ikhana GCS
  - Vigilant Spirit Integration
- Airspace





# Integrated Test and Evaluation



FY	Technical Activity
FY12	Integrated Human-In-The-Loop and Flight Test Concept and Objectives development
FY13	Live Virtual Constructive – Distributed Environment development/evaluation
FY14	Integrated Human-In-The-Loop simulation
FY15	Integrated Flight Test Series 3
FY16	Integrated Flight Test Series 4

**Document**

**Build**

**Tailor**

**Tailor**

**Tailor**

## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

## Standards/Regulations

Validate minimum system and operational performance standards and certification requirements and procedures for unmanned aircraft systems to safely operate in the NAS

## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



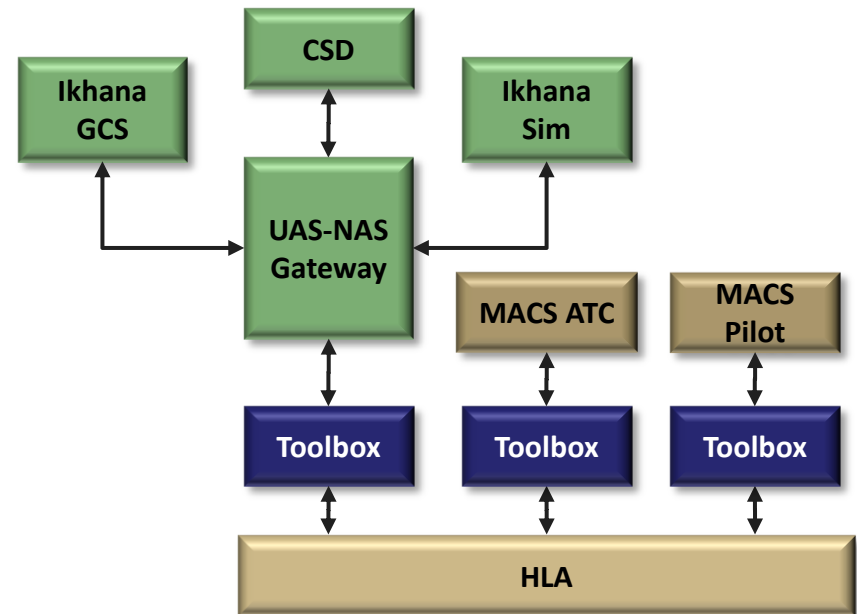
# Technical Activity: Build

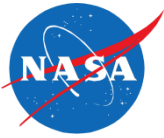


- Live Virtual Constructive – Distributed Environment development and evaluation
  - Build and test LVC-DE infrastructure
    - Flight Test 1
    - Flight Test 2
  - Develop and test candidate technologies through part-task and fast-time simulation

# Flight Test 1

- Flights concluded May 11, 2012
- UAS ADS-B In/Out Flight Tests
  - Installed ADS-B on Ikhana
  - Verified via ADS-B/TIS-B real-time tracking surveillance (RTTS) capability
  - Telemetry data sent to LVC-DE
- Leveraged existing LVC-DE infrastructure
  - Established a gateway at DFRC to connect the Ikhana telemetry data
  - Distributed data to local cockpit situation displays (CSD) and to air traffic control (ATC) workstations at ARC
  - Simulated data from ARC displayed on CSD at DFRC
  - Integrated Ikhana Pilot Simulator

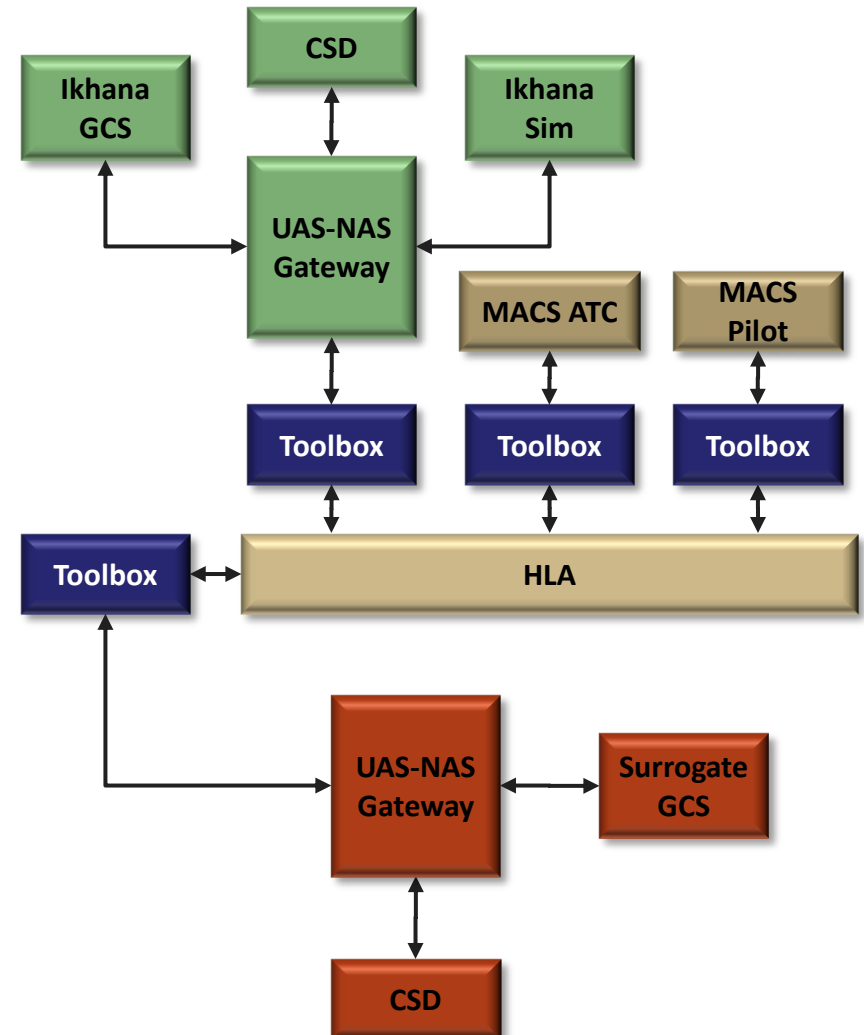




# Flight Test 2



- Scheduled May/June 2013
- Flight test of prototype Communications equipment
  - Collect real-world communication latency data to compare against simulation latency data
  - Connect to LVC
    - DFRC and GRC
    - Translate Flight coordinate system to representative airspace
  - Integrate HSI GCS display and SSI algorithms to the extent possible





# LVC Component Testing



- Ongoing testing
- Investigate Data latency
  - Availability of data to users and algorithms
  - Determine latencies between simulation sources (GCS, Pseudo Pilots, etc) to compare with observed communication/data latencies
    - Network latencies
    - Software induced latencies
  - May need to add/mitigate lag
- Connect alternative aircraft telemetry data to LVC
  - Between GRC, DRFC, and ARC
  - Late summer 2012
- Install simulation voice communication (Simulation ATC/Pilots)
- Augment GCS displays
- Integrate Sense and Avoid algorithms



# Integrated Test and Evaluation



FY	Technical Activity
FY12	Integrated Human-In-The-Loop and Flight Test Concept and Objectives development
FY13	Live Virtual Constructive – Distributed Environment development/evaluation
FY14	Integrated Human-In-The-Loop simulation
FY15	Integrated Flight Test Series 3
FY16	Integrated Flight Test Series 4

**Document**

**Build**

**Tailor**

**Tailor**

**Tailor**

## Airspace Integration

Validate technologies and procedures for unmanned aircraft systems to remain an appropriate distance from other aircraft, and to safely and routinely interoperate with NAS and NextGen Air Traffic Services

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## Relevant Test Environment

Develop an adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS



# Technical Activity: Tailor



- Integrated Human-In-The-Loop simulation: March/May 2014
  - Evaluation of candidate SSI and HSI technologies
  - No live aircraft
  - Communication latencies derived from Fight Test 2 outcomes
- Integrated Flight Test Series 3: Feb/March 2015
  - Evaluation of candidate SSI, HSI, and Communication technologies
  - Live aircraft
- Integrated Flight Test Series 4: January/Feb 2016
  - Evaluation of candidate SSI, HSI, and Communication technologies
  - Live/multiple aircraft, more complex scenarios
- Test planning and integration efforts built into event scheduling:
  - Test Plan Development (including scenario building): 12 months prior
  - Software testing: 6 months prior
  - Simulation Shakedowns: 2 months prior





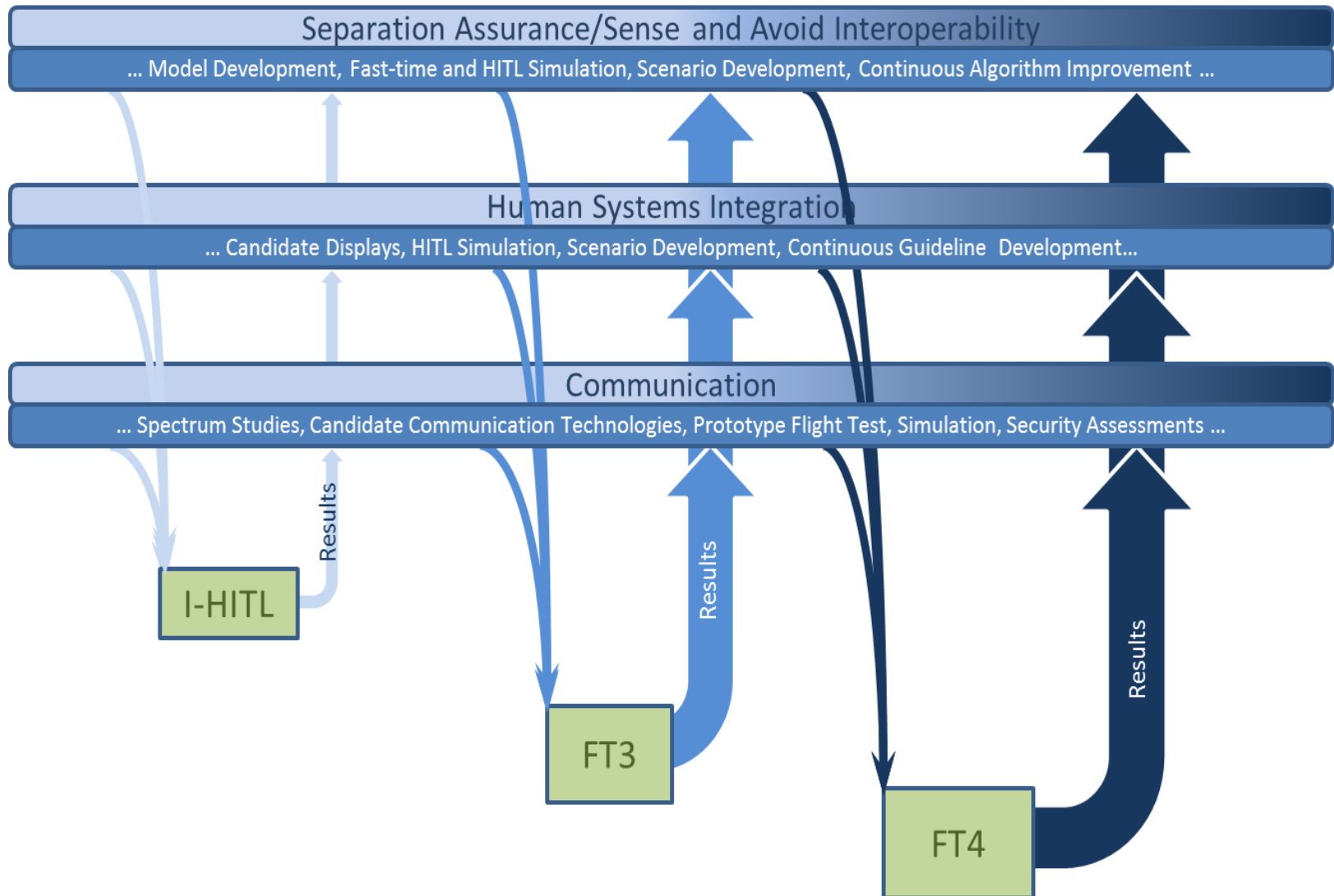
# Accomplishments



- Prototype LVC
  - Display of live and simulated traffic on GCS display and ATC workstations
  - Distributed between Ames and Dryden
- Connection to/from FAA Tech Center
  - ADS-B/TIS-B feed from real-time tracking surveillance (RTTS) capabilities
  - Live aircraft for scenario building
  - Testing connection via NextGen R&D network
- Flight Test 1
  - Concluded May 11, 2012
  - ADS-B installed on Ikhana
  - Telemetry data sent to LVC-DE for display
- Simulation Voice Communications
  - Building software bridge to link disparate solutions available at Ames, Dryden, and FAA Tech Center



# Linkages and Integrated Events





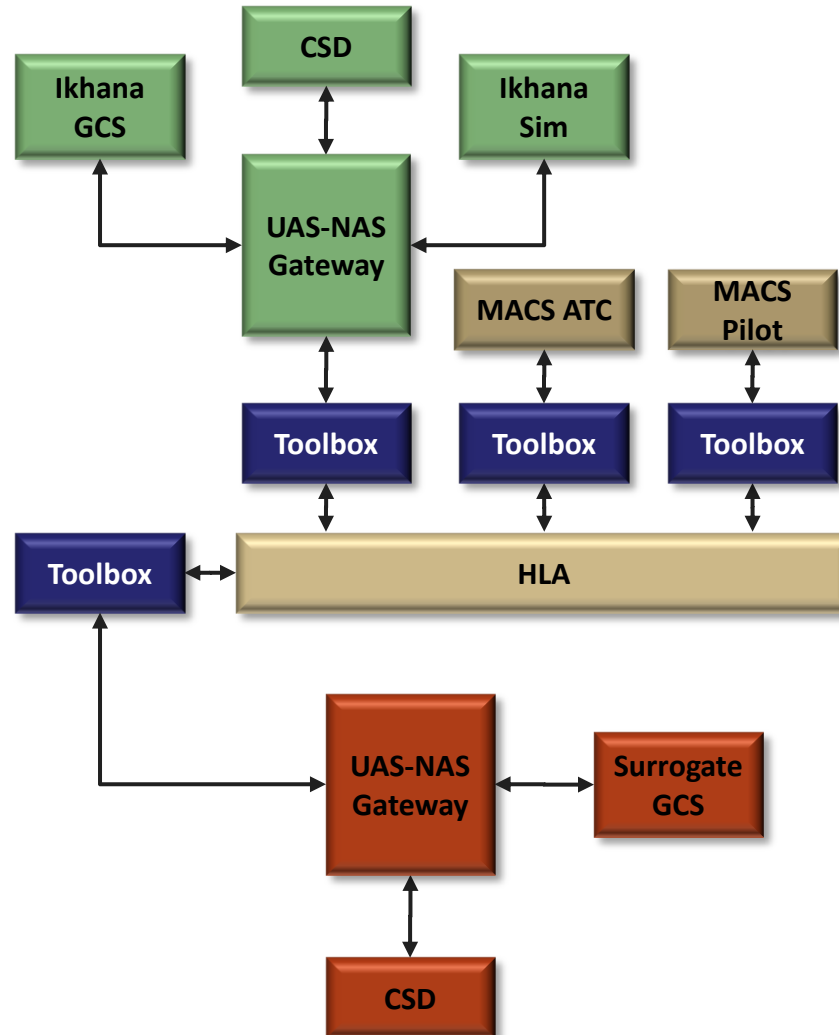
# Enabling External Collaboration



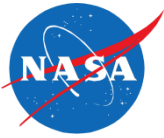
- We are looking for opportunities to collaborate with FAA, BAMS, and DoD Airspace Integration
- Share scenarios
- Share airspace assets
- Share flight assets
- Share simulation components
  - May need to build interface
  - Connection to LVC-DE
    - Establishing connection to FAA NextGen R&D network
    - Cross Domain Solution (CSD) used to connect to DoD for BAMS
- Share events



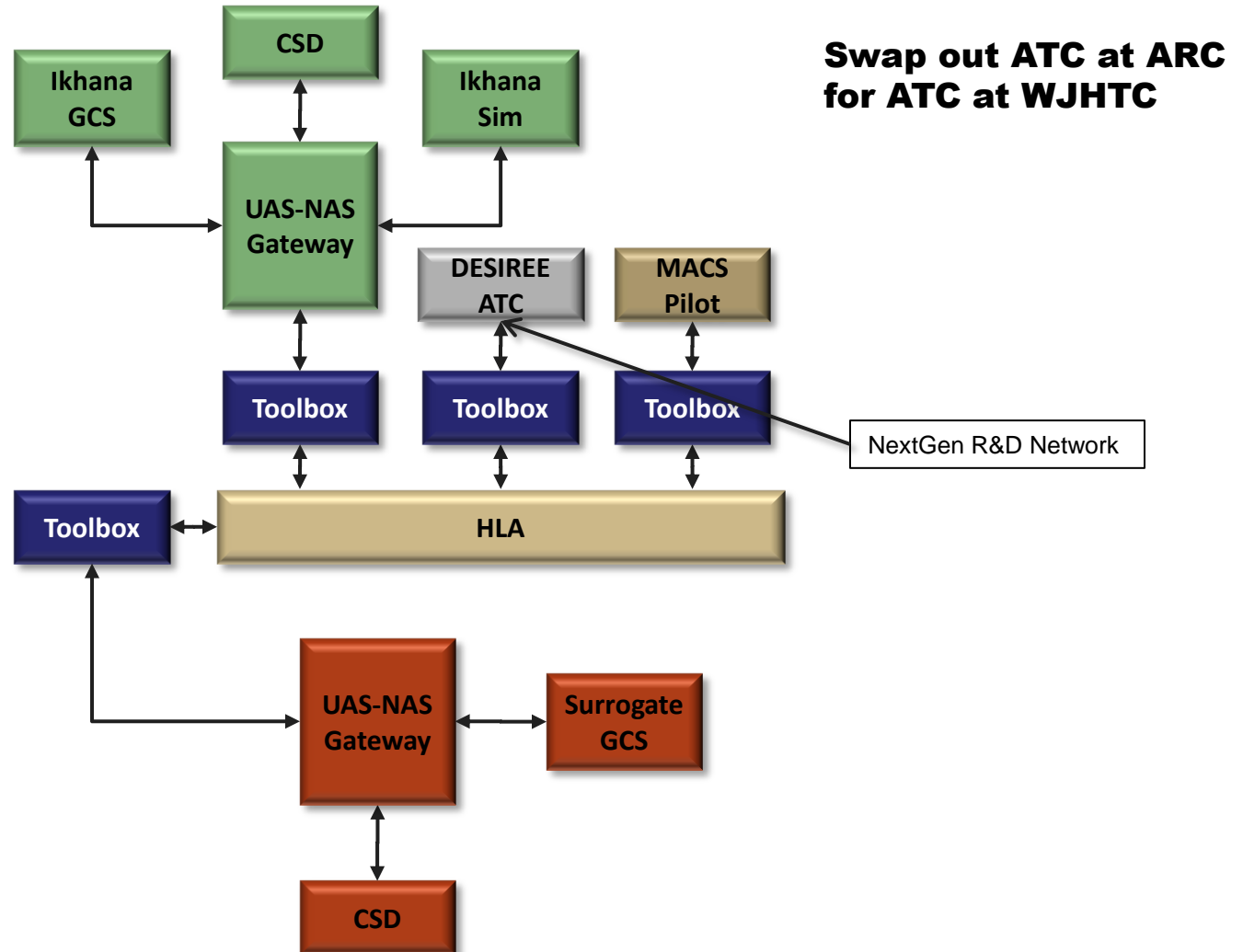
# Collaboration Infrastructure



**Start with Flight Test  
2 Configuration**



# Collaboration Infrastructure

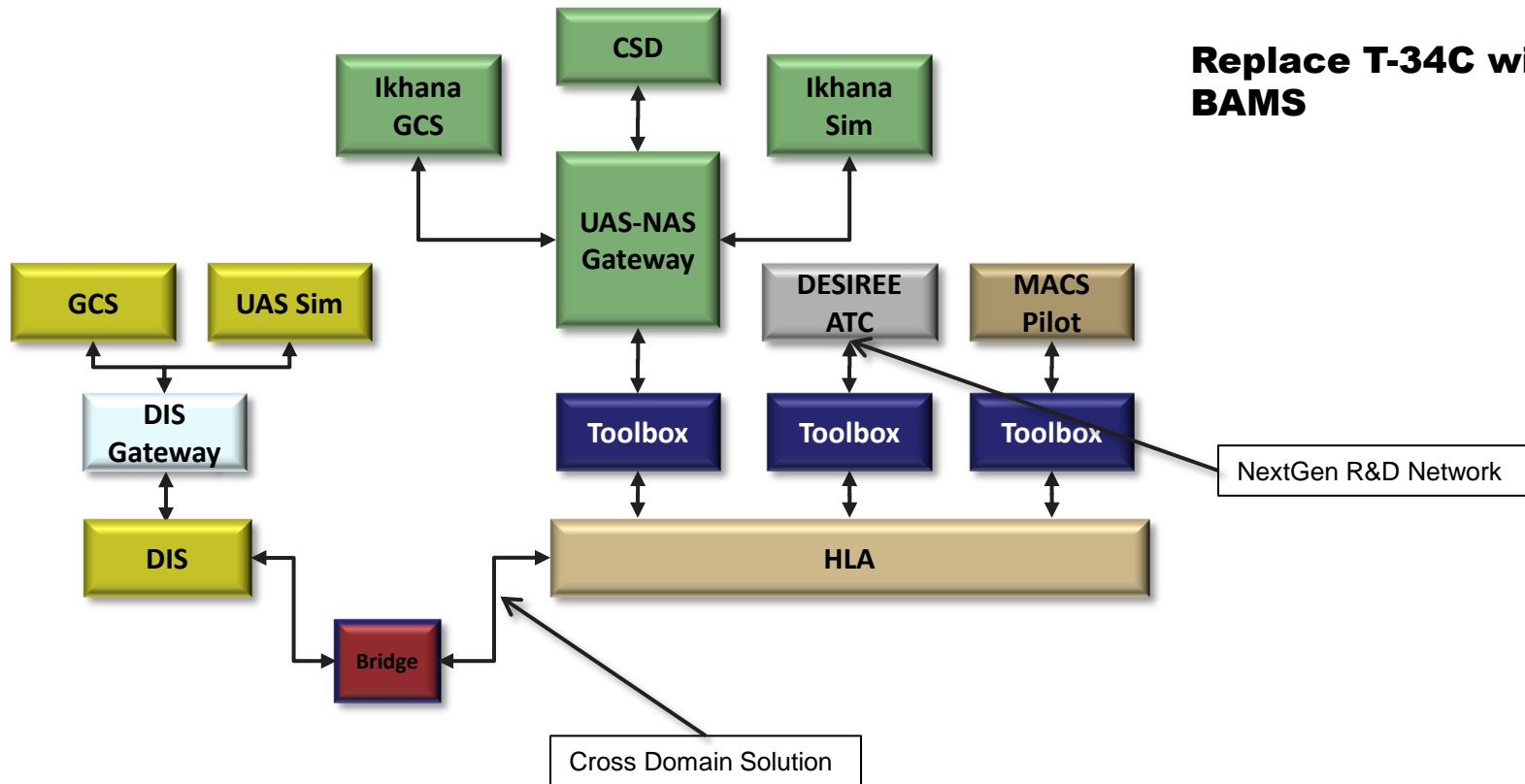




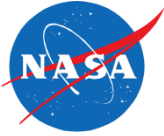
# Collaboration Infrastructure



**Replace T-34C with BAMS**



Goal: Build LVC-DE that allows interchangeable components to support varying levels of fidelity and functionality



# Summary



- Building LVC-DE infrastructure to meet Project simulation and Flight Test requirements
- Testing interfaces to support connection to external partners
- Long-term leave behind simulation capability



# Questions?

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# Back-up Charts



# Airspace Assets

